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Calibration of Computer Program for Radar Waveform Analysis

— Final Report

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Abstract:
This report describes DART (Deck Assessment by Radar and Thermography), a hardware and software system that uses ground penetrating impulse radar and thermography equipment mounted in a van. The van drives over a bridge deck, and the DART system detects various forms of deterioration such as delamination, scaling, and debonding in asphalt covered decks.

The computer algorithms employed were based on the physical characteristics of one particular bridge deck, which was investigated in the field using conventional techniques as well. Four different types of bridge deck were subsequently tested with the DART system to see how the equipment and algorithms should be changed to provide a more universally applicable deck assessment tool. The results are reported herein.

In addition to a detailed description of the DART hardware and software, the report describes general operation of the system. The researchers conclude that the DART technique is valid and cost-effective for certain conditions. Recommendations are made for further research and analysis.

Key Words: radar, thermography, deck assessment, structures, durability, deterioration, bridge decks

Comments:

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Calibration of Computer Program for Radar Waveform Analysis
— Final Report

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EXECUTIVE SUMMARY

The goals of this project are to develop a new Deck Assessment by Radar and Thermography (DART) system which will interface with an existing radar system and process the returns from bridge deck structures. In this program, real data were collected from two asphalt overlay structures and one exposed concrete deck. In addition, data from a previous field trip were available for analysis.

The DART system comprises:

- an input interface board which allows the digitization of radar data at a sampling rate of 25,000 samples per second;
- a computer system with large computer memory, a hard disk, a co-processor and a colour monitor; and
- a printer and plotter combination for outputting the computed results.

In addition, there are software packages for inputting the data and for plotting.

Processing algorithms already developed for a previous program have been loaded into the DART system and tested using the collected data sets. In general, it is seen that the asphalt overlay decks can be successfully analysed to obtain asphalt thickness, determine the condition of the interface between the asphalt and concrete (with and without a membrane) and detect delaminations. All different asphalt types were tested and it is concluded that the radar signal penetrates asphalt with no problems.

For exposed concrete decks, the location of asphalt patches is straightforward. However, the radar was not successful in detecting delamination due to the large surface reflection which masks the small reflection from the delamination.

By employing a control track on the tape recorder, the system can be operated in the laboratory or office environment in an automatic mode which analyses the data with a minimum of operator input. In the field, the system can be linked directly to the radar and used to provide an on-site evaluation of the data being collected. Measurements conducted indicate that the processing speed of the system is approximately 2 s per linear metre of data. Since the vehicle speed is approximately 1.5 m/s, the DART system is well matched in processing speed to the collection of data.

1/ INTRODUCTION

The Ontario Ministry of Transportation and Communications (MTC) is actively developing the use of ground penetrating impulse radar as a tool to detect various forms of deterioration, such as delaminations, scaling and debonding in asphalt-covered bridge decks. In a previous study [3], a computer program was developed to analyse the raw radar waveforms generated by the impulse radar.

The computer algorithms employed in this project were designed on the basis of the physical characteristics of one bridge deck. While typical of many structures, a number of variations in design require testing. These variations include:

- various waterproofing systems;
- different mix designs for wearing courses;
- decks having significant cracking and/or repairs in the wearing surface; and
- exposed concrete decks.

The overall objectives of the project are summarized as follows:

1) Assess the validity of the present algorithms for these variations.

2) Design the necessary subroutines and changes necessary to accomodate the testing of these variations.

3) Update the present program to accomodate these subroutines and changes.

The final algorithms will allow testing of any structure within the MTC system regardless of the type and condition of the structure.

1.1/ Project Specifics

The specific objectives of the project comprised four separate Tasks.

TASK 1

1) Develop a new Deck Assessment by Radar and Thermography (DART) system which will interface with the existing radar system and a new data acquisition tape recorder. The DART system will become the property of the Ministry at the end of the contract.

2) Process the Papineau Creek data using the DART system and ensure that the results are identical to those obtained using the HP 1000 computer. This will provide a benchmark trial which will prove useful when processing bridge decks with structure similar to that of Papineau Creek.

TASK 2

3) For the four different structural features which have been identified (namely; waterproofing, mix design, cracking, and/or repairs in the wearing surface and exposed concrete decks) examine a suitably small set of radar waveforms from different bridge decks and evaluate the characteristics of these waveforms using both visual observation and DART-based waveform analysis. In particular, it is important to relate the actual structure of the bridge deck producing these radar waveforms to the radar returns being observed. Factors to be considered include:

   a) detection and identification of the waterproofing layer;

   b) measurement of dielectric constant and asphalt thickness for the different types of asphalt mix;

   c) identification of radar waveform signature for areas of cracking and/or repairs; and

d) waveform characterization for areas of exposed concrete.

Analysis will be performed in the time domain relating the features of the waveforms to the structure of the bridge deck.

TASK 3

4) The procedure used in the present algorithms will be evaluated with the data sets from the signals described above in 3) parts a) through d). Where modifications are required, new programs will be developed which are compatible with existing software. These new algorithms will be tested with real data sets to ensure proper operation over the range of expected signals.

TASK 4

5) The new software package will be tested with sets of data collected from selected bridge decks. The four areas of interest identified in Task 2 will be highlighted to show system performance. Software will be developed to produce printouts and/or plots of processed data indicating asphalt thickness (where applicable), measurement of the waterproofing layer (where applicable), areas of deterioration and repair and/or cracking, and waveforms from areas of interest.

1.2/ Overview of Report

Section 2 provides a description of the new DART system and lists the different hardware components which comprise the system. Section 3 discusses the development of the programs for the DART system. Sections 4, 5, 6 and 7 deal with the processing of data from Papineau Creek bridge, Nith River bridge, CPR Overhead and Burnhamthorpe Overpass, respectively. Section 8 provides the Method of Operation and Section 9 gives Conclusions.

2/ THE DART SYSTEM

2.1/ Description

Figure 2.1 is a block diagram of the new DART system. It is centred around an IBM-XT personal computer. In the field, this computer acts as a data acquisition controller and data processor. In the laboratory, it serves in addition as a software development aid. The major specifications of the computer are:

- 16-bit 8088 microprocessor
- 576k computer memory
- Double density floppy disk controller
- DMA and interrupt controller
- IBM-XT keyboard port
- Winchester hard disk interface
- Peripheral module with dual 5-1/4 inch floppy disk capability
- Programmable tone generator/speaker
- Eight IBM-XT expansion board slots

An array of peripheral units and options is also included:

- 8087 arithmetic co-processor
- CRT controller
- IBM keyboard
- IBM high resolution colour monitor
- Epson RX-80 dot matrix line printer with graphics
- Tecmar Labmaster data acquisition interface card
- Custom-made filter circuitry for radar video signals
- Custom-made digital counter interface for 5th wheel signals
- Teac 7-channel tape recorder
- HP 7475A multi-pen colour digital plotter

The data acquisition functions are performed through the Labmaster's analog-to-digital converter by sampling the tape recorded data at its inputs. Any one of seven tape recorder channel outputs are sampled at 25 kHz. These are:

- Radar high video
- Radar gated video
- Radar sync trace
- Bridge line sync
- 10 cm fifth-wheel pulses
- 1 m fifth-wheel pulses
- 10 m fifth-wheel pulses

DART

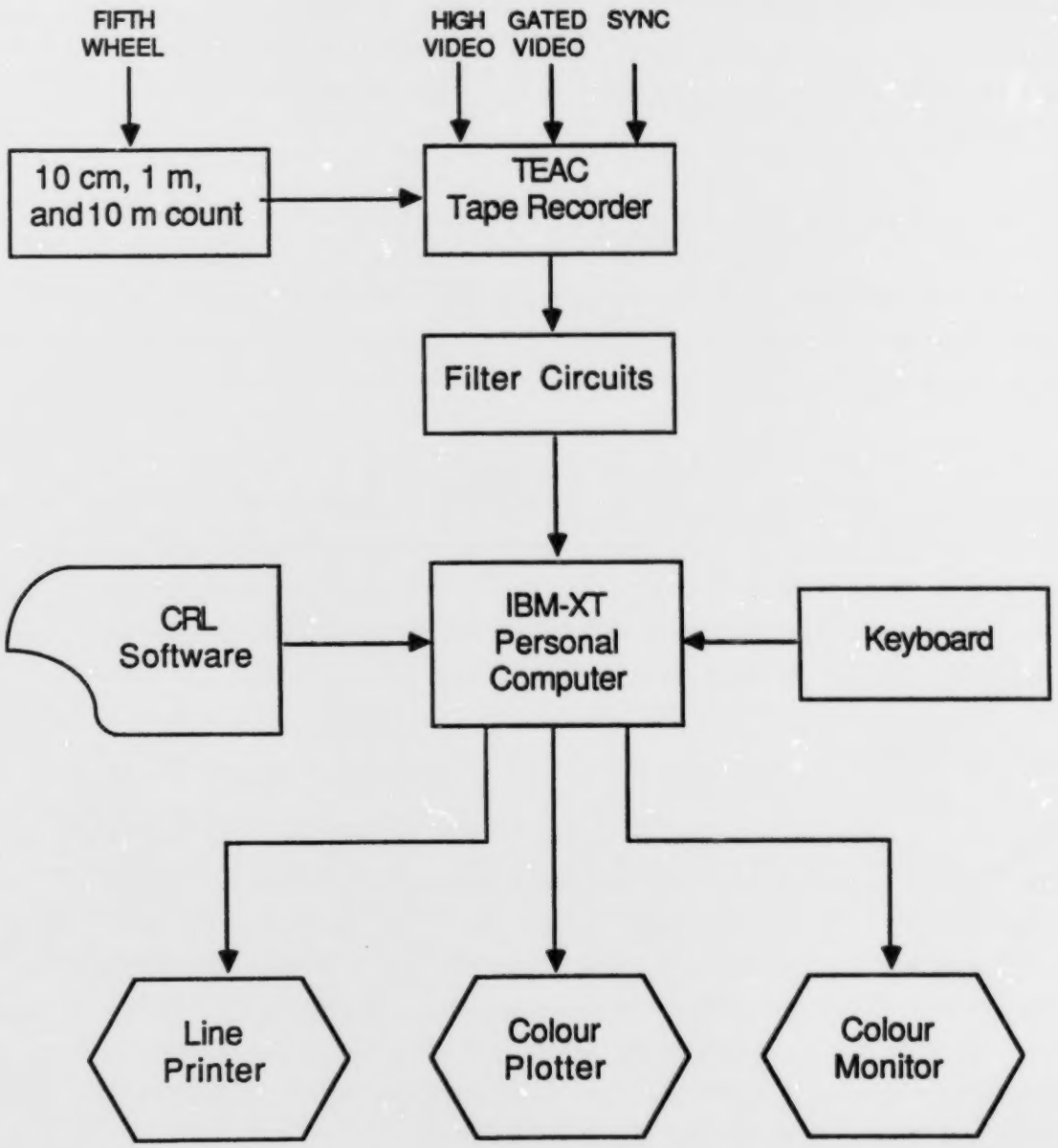


Figure 2.1/ Configuration of the DART System

The radar high video, radar gated video and radar trace sync are simply the standard video outputs from the radar. In addition to these, we record a control track (called the bridge line sync) on the tape recorder. This is used to instruct the computer to process tape recorded data. The bridge line sync signal provides a monitor for such functions as flat plate measurement, beginning of line, end of line and end of bridge deck recording.

The set of three 5th wheel pulses provides a coded set of waveforms which can be used to locate the position along any line. This is important in cases where the line being recorded exceeds approximately 90 m. In this case, the tape recorder can be stopped in order to transfer the data to the hard disk without losing the location on the tape.

Since all the data in the radar gated video signal are contained in the radar high video, the former signal is not used. In addition, the radar sync trace can be replaced by simply scanning the data for the surface reflection which is always prominent. Thus, the programs developed in this project require the use of the radar high video signal; the bridge line sync; and the 10 cm, 1 m, and 10 m fifth wheel pulses.

2.2/ Operation

There are two different modes of operation for the system. The first mode, called DETAILED ANALYSIS, assumes operation of the system in the laboratory or a clean office environment where the computer (and its associated hardware), colour monitor, tape recorder, printer and plotter can all be interconnected and the recorded data processed with little operator attention. The data are taken from the tape recorder and processed using the programs stored in the computer memory with results appearing on the line printer or in the plotter.

The second mode of operation, called QUICK LOOK, assumes operation in the van where the printer and plotter may not be available. In this case, the objective is to obtain an "on the site" indication of the bridge deck condition and the results are displayed using the colour monitor. In this mode of operation, no use is made of the hard disk and analysis is

provided for only one line at a time. The programs for processing the data and programs controlling these two modes of operation constitute the overall software package.

2.3/ Comparison with Previous System

The major difference between the new system and the HP 1000-based system developed by CRL last year can be summarized in point format:

HP 1000 System

1) Interfacing to the data tape recorder was awkward.

2) This data acquisition task had to have top priority on the system; i.e., no other users were allowed to use the computer simultaneously. About 4 hours were needed to perform this task on the Papineau Creek bridge deck.

3) Subsequent data processing could not be left unattended. The processing speed was an additional 4 hours to do Papineau Creek.

4) The HP 1000 is a fixed installation; it is not portable in the field.

5) HP software is very inflexible and incompatible with other companies' software unless it is substantially modified.

New DART System

1) Interface hardware and software are much simpler through the Labmaster board.

2) With no other users on the system, all of the radar data may be input to the hard disk via computer memory and left there for subsequent processing. Thus, it is no longer necessary to store the digitized data back out onto digital tape.

3) Data processing speed is faster than with the HP 1000 since control of the data can be written in assembler code specifically intended for the application.

4) The equipment is field portable.

5) The software is flexible and fully IBM compatible for future modifications.

3/ PROGRAM DEVELOPMENT

3.1/ Software Overview

A chart listing the new system software, called Program Modules, is presented in Figure 3.1. Each block in the system represents a program module, described by its function. The chart details the program modules in their order of execution. The operation of the programs is described in detail below.

3.2/ Data Acquisition

A central problem in the new system software development is the reduction of data volume by the computer while preserving all desired information in the radar data. This data reduction task faces a major problem: namely, the data recorded by the tape recorder is played back into the computer at a certain speed. Some control is permitted in that the tape speed is selectable and the recorder may be started and stopped when necessary. In addition, the tape may be rewound in order to read data starting at any location. Nevertheless, the input data stream must be stored using a large memory.

Initially, it was intended to use the DART system hard disk unit as a mass storage unit (up to 10 megabytes) for random access storage from the input. This unit, however, cannot be filled with data in real time due to the DOS overhead, and also due to the computer being based on a single processor machine. In essence, data cannot be sampled into computer memory and transferred onto the hard disk simultaneously.

The alternative is to input a portion of data into computer memory, and then stop the tape recorder while the data are transferred from computer memory onto the hard disk. The process can then be repeated by starting the tape recorder again and so on until the whole bridge deck has been sampled. Using the computer memory as an intermediate data buffer in this way has been done successfully with assembly language programming. Assembly language was necessary to handle the high speed requirement of data sampling and data management essentially in real time. Approximately 410,000 bytes of data can be sampled into the computer memory buffer before the tape recorder must be stopped while the data are off-loaded onto a hard disk file.

PROGRAM MODULES

	TASK	PROGRAM
1	Sample flat plate recording or any other stationary measurement.	PLATE
2	Sample bridge line data synchronized to fifth wheel gating impulses.	ADC98
3	Plot raw data binary disc files using monitor screen and graphics plotter.	PLOT
4	Process bridge line raw data disk files, and display processed output (asphalt thickness, scaling, debonding and delamination) on monitor screen and line printer.	MTC
5	Plot bridge deck layout and indicate areas of scaling, debonding and delamination.	PLOTDECK
6	General purpose burst sampling of a tape recorder channel in increments of 64K bytes.	ADC45

Figure 3.1/ Program Modules

The programs PLATE, ADC98 and ADC45 are written in assembly language. Both PLATE and ADC98 are enhanced versions of the program ADC45. The intent of these software packages is to perform data acquisition such that the real data can be converted from analog to digital form for signal processing. ADC45 is a stand-alone menu-driven program that allows the buffer size to be manually set in increments of 64k blocks, up to a maximum of eight. ADC98 can be used as a function call from the Fortran Monitor Program.

3.3/ Data Processing

Data reduction in the data acquisition programs is accomplished in two different ways. First, for all waveforms, the first half of the trace is considered to contain useful data and the last half is assumed to be irrelevant. Thus, only the first 10 ms of data are permitted to enter data processing subroutines. The second 10 ms slot is used by the computer to compute the average level of the trace and zero-average adjust the trace. All data inputs, such as ADC98 and PLATE, benefit from this data reduction procedure. In addition, for data that are processed using fifth wheel information (such as ADC98), the 10 cm fifth wheel waveform is used to ensure that footprints are taken only every 10 cm.

Thus, regardless of the speed of the van (provided that at least two traces are always available), the data set entering the computer is kept to a near minimum. This is especially important where slow van speed can cause huge quantities of redundant data.

With these data reduction techniques, it is possible to load computer memory with 900 separate radar traces which corresponds to 90 m of bridge deck. At this point, the tape recorder must be stopped to allow off-loading of the data onto the hard disk in the form of a raw-data binary file. These raw-data binary files are used subsequently as inputs to the detailed processing programs.

The program MTC, written in standard Fortran 77 language, performs all processing functions such as calculating the depth of asphalt, determining the R1/R2 ratios for scaling and debonding, and providing the zero crossing count for delamination detection. The software is designed to

handle analysis for a bridge deck of 90 m in length with 10 grid lines. The processed results are stored as formatted data files for future reference and are also output, in tabular form, to the monitor screen and the line printer.

The PLOT program was developed using a commercial plotting package PLOTMS.LIB and GRAFMS 2.LIB. The program makes possible a quick visual examination of the digitized radar waveform. Individual waveforms can be plotted on the monitor screen or can be output to the HP 7475A graphic plotter. PLOTDECK indicates the areas of deterioration on a grid-formatted layout which represents the actual bridge deck. This output can only be produced on the graphic plotter.

3.4/ Detailed Program Analysis

The important changes to the software developed for the HP 1000 computer relate to the storage of data and access by the processing algorithms. Large savings in execution time have been realized by storing a complete bridge line of raw data in computer memory while simultaneously resident Fortran operates on the data. In order to fit a reasonable size bridge line of raw data in computer memory, the data are stored in integer format (Fortran array) representing the actual digital samples produced by the sampling programs. This results in only two bytes/sample (12-bit A/D converted data) instead of the four required if floating point format is used.

The processing algorithms have also been modified in part to make use of integer data. It is not necessary to "float" the raw data samples for certain of the processing operations such as sorting and counting. This then results in much faster algorithm execution. Intermediate results are then "floated" only when it becomes necessary to retain fractional numbers, such as in division (ratio calculations) or in multiplication by a fractional constant (depth calculations). These conversions to floating point number formats and subsequent floating point operations are done with the 8087 arithmetic coprocessor chip, which results in a factor of at least 3 or 4 times increase in speed.

Computer memory size limitations restrict the allowable number of radar traces to 900 (each having 256 samples). If the 10 cm fifth wheel gating pulse is used, then analysis can be provided for an 90 m length of bridge deck. If the 1 m fifth wheel gating pulse is used, the 900 m of bridge deck can be analysed. Finally, if the 10 m fifth wheel gating pulse is used, then 9000 m of bridge deck can be processed. Note, however, that as the length increases, the accuracy of the determination is diminished.

4/ PROCESSING OF PAPINEAU CREEK DATA

4.1/ Data Set

The data from Papineau Creek bridge deck recorded in the summer of 1983 were reprocessed using the new DART system configuration. These data, stored by the HP 1000 computer on digital tape, were transferred to the new system through the RS-232 feature of the microcomputer. Once in the microcomputer, the data were transferred to floppy disk for permanent storage.

In order to demonstrate the versatility of the new system, the data were processed from the floppy disks rather than directly from the incoming data at the RS-232 input. The processing of these data is now examined in detail and the results are compared to those obtained using the HP 1000 system.

4.2/ Selected Waveforms and R1, R2 Ratios

A set of waveforms were plotted at selected locations on line B, as illustrated in Figure 4.1. We see examples of good deck (6 m), delamination (6 m), and debonding (36 m). These results are in good agreement with the previous findings.

The R1 and R2 ratios for line B are plotted in Figure 4.2. Comparing with the results obtained previously for the B line, shown in Figure 4.3, we see that the agreement is reasonably good, with the exception that the R1 ratio is shifted upwards. This difference is due to the new software package which automatically zero-averages the input waveform. The previous package did not include this feature. Note that for Figure 4.1, the voltage waveforms near the 10 ms time interval decay almost to 0 V. This minor change requires only that the threshold for debonding and scaling be adjusted. The R1 ratio is essentially unchanged.

From the plots of R1 and R2, we can identify the areas of debonding and scaling for the overall bridge deck. These plots, given in Figures 4.4 and 4.5, respectively, can be compared with the previous plot of Figure 4.6. We note that:

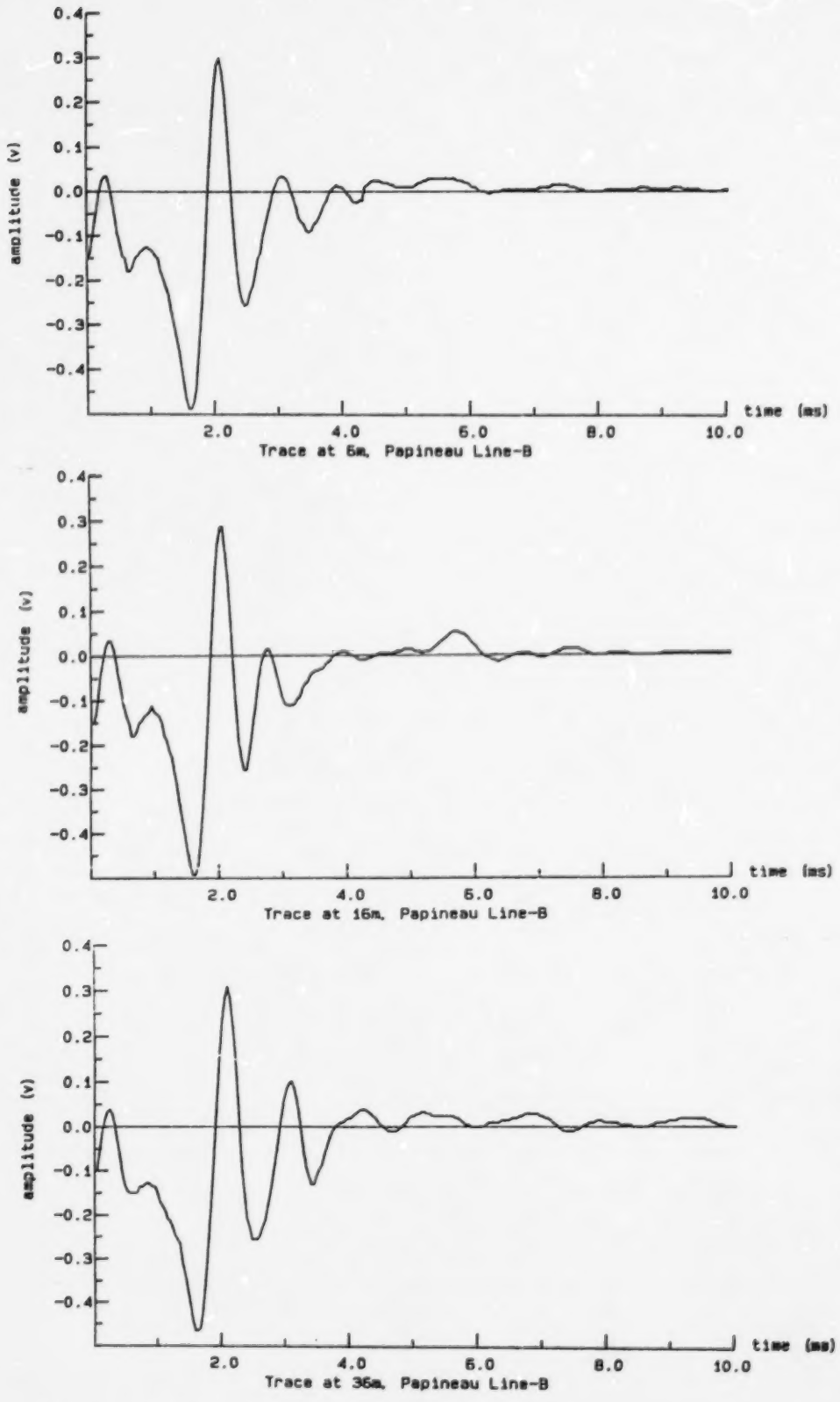


Figure 4.1/ Waveforms Plotted at Selected Locations on Line B

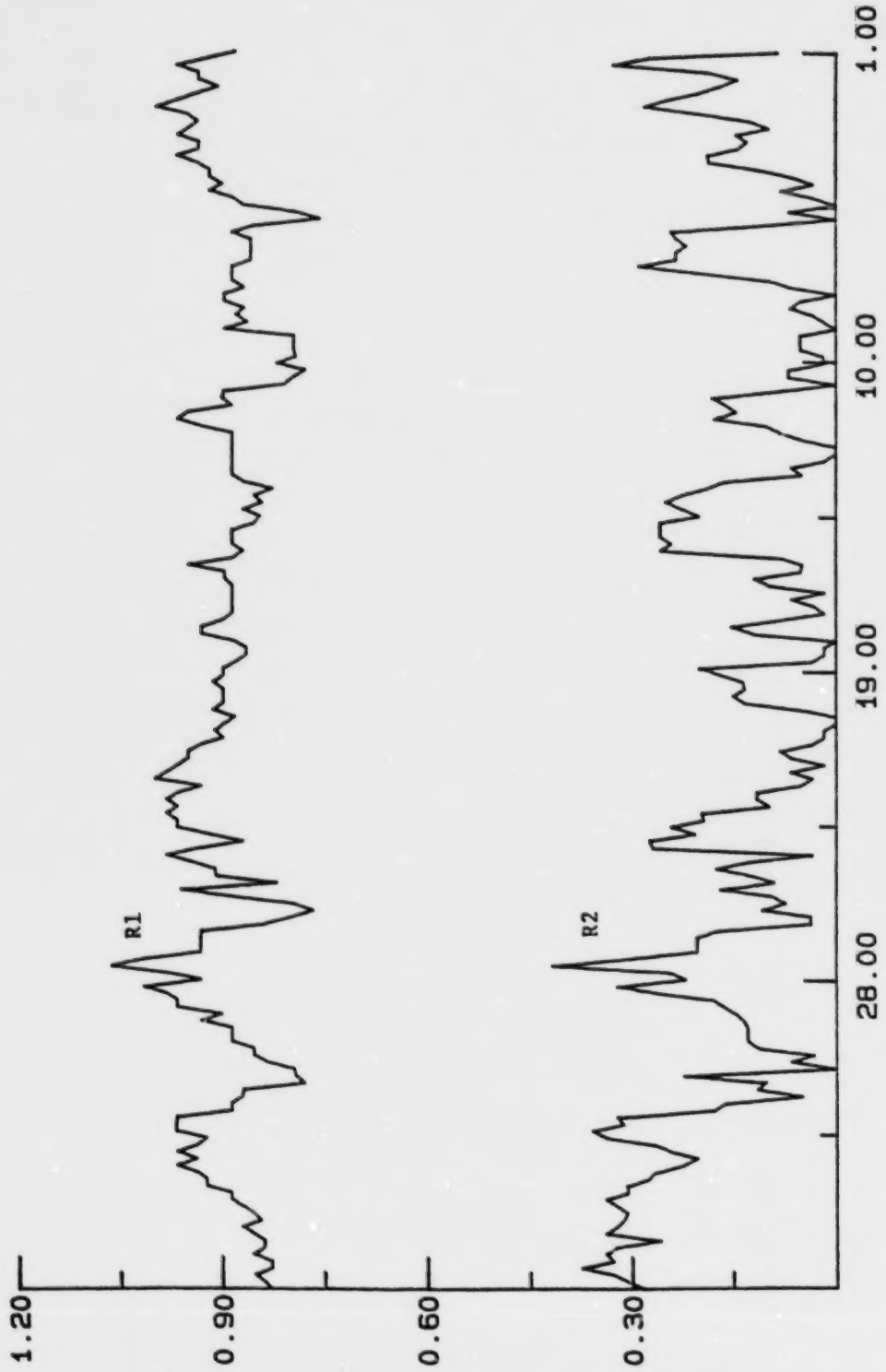
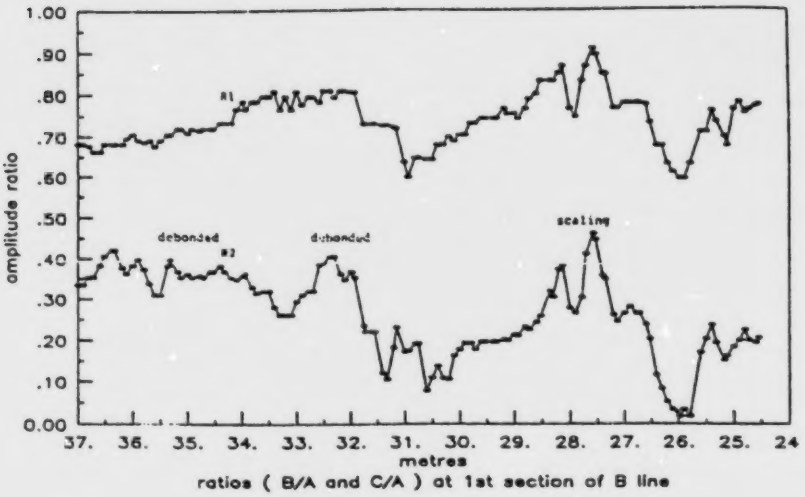
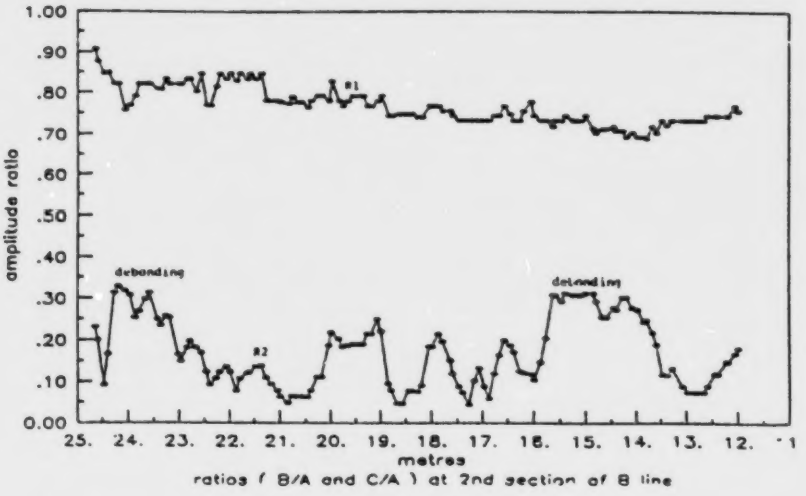


Figure 4.2/ R1/R2 Ratio Plots for the B-line Using the DART System





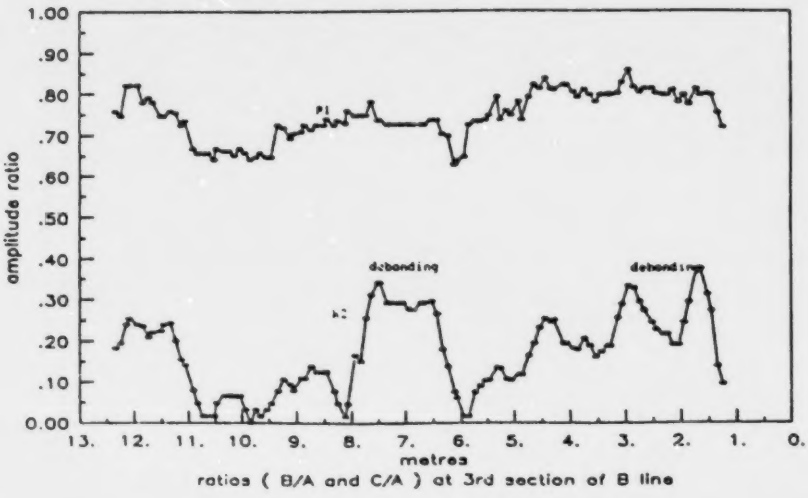


Figure 4.3/ R1/R2 Ratio for the B-line Using the HP 1000 System

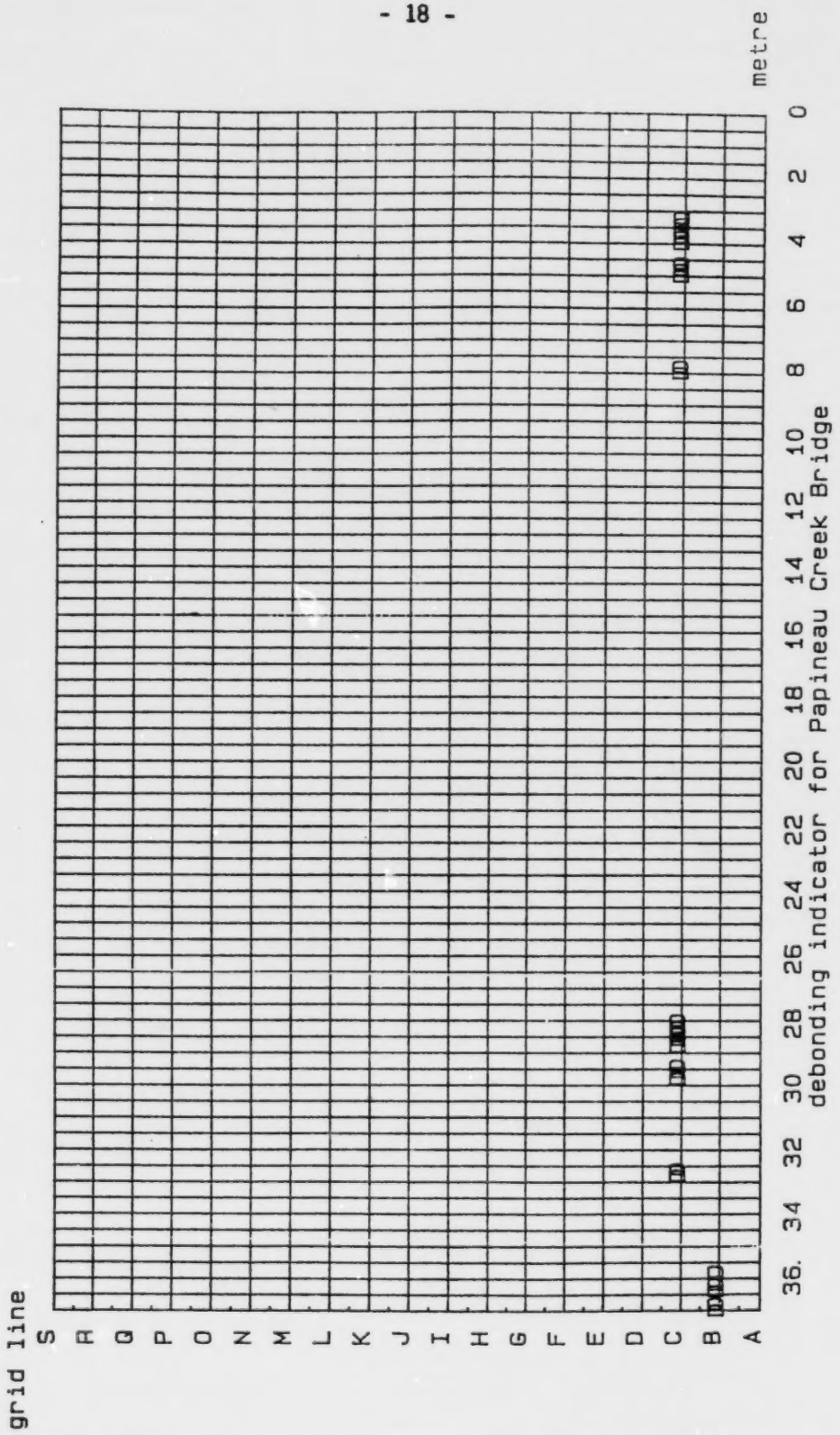

grid line
S R Q P O N M L K J I H G F E D C B A
36. 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
metre
debonding indicator for Papineau Creek Bridge

Figure 4.4/ Debonding Plot for Papineau Creek Bridge Deck Using the DART System

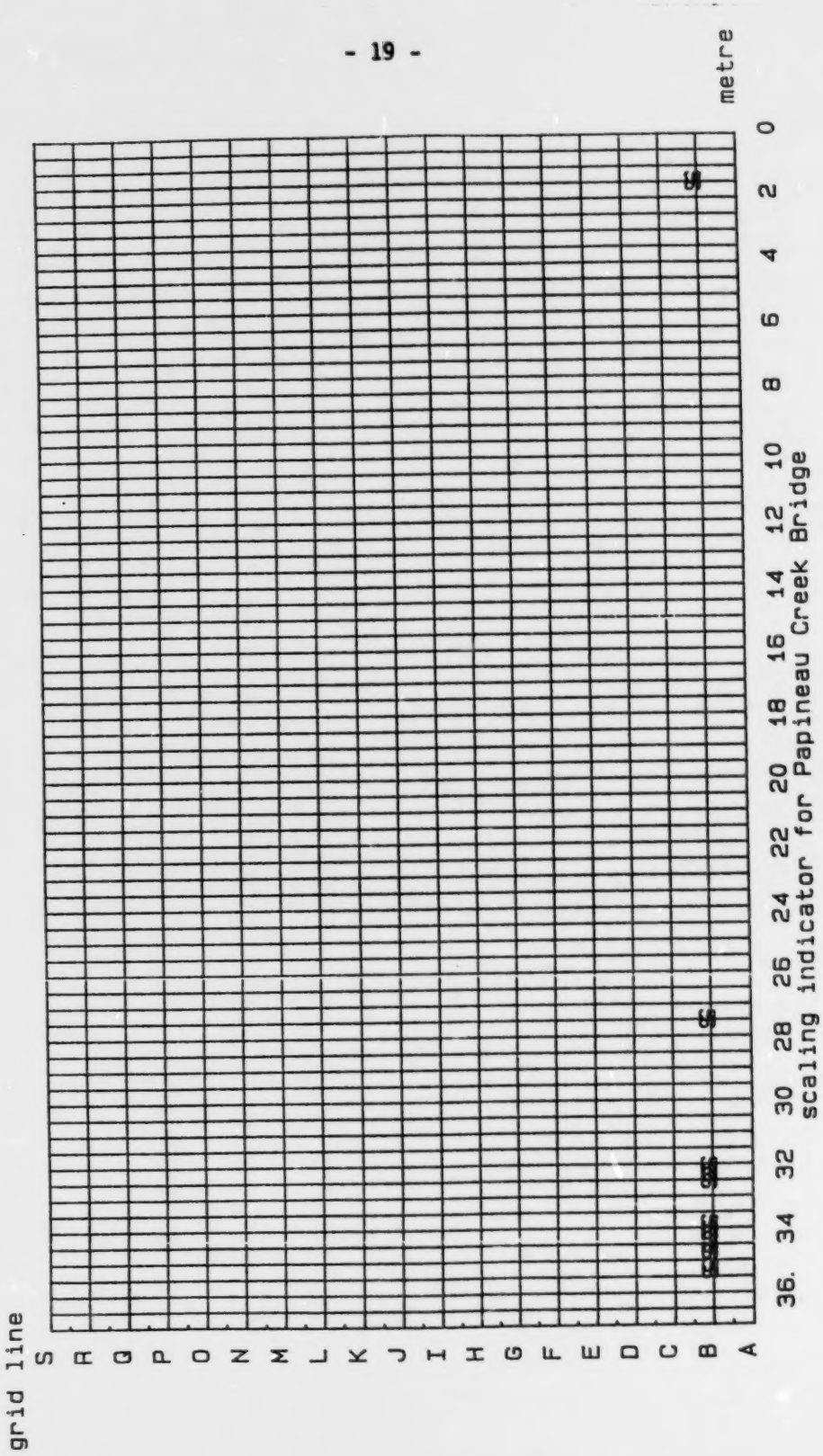

metre
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36.
scaling indicator for Papineau Creek Bridge
grid line
A B C D E F G H I J K L M N O P Q R S

Figure 4.5/ Scaling Plot for Papineau Creek Bridge Deck Using the DART System

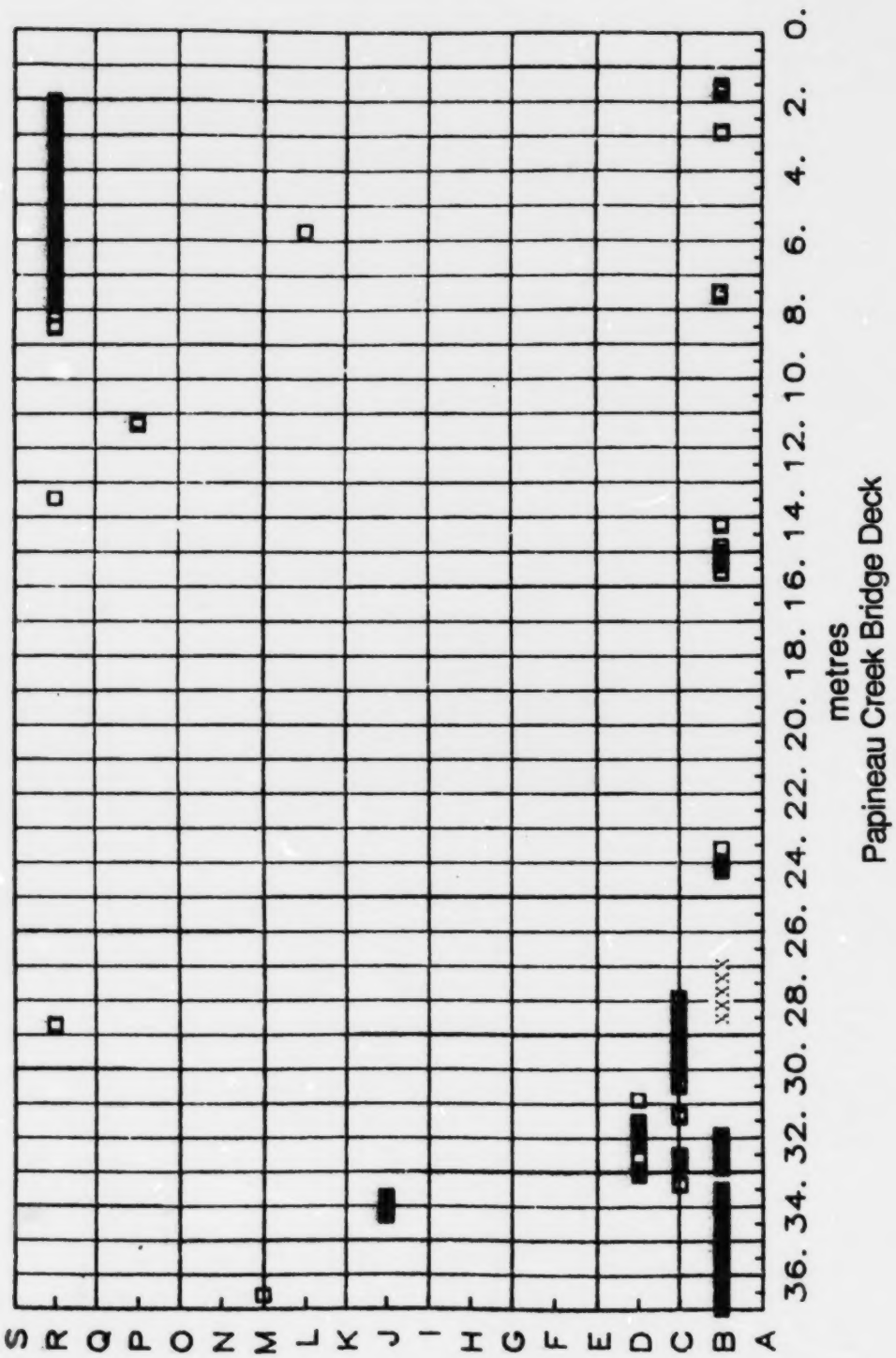


Figure 4.6/ Debonding (O) and Scaling (X) Plot for the Bridge Deck Using the MP 1000 System

1) For both systems, there is very little debonding or scaling detected (which is the correct result).

2) For debonding, the new system eliminates some of the false indications produced by the old system; however, the areas which were deliberately debonded with talc are still not detected since the talc does not represent an air gap.

3) For scaling, the new system detects a few areas not detected by the old system or areas that the old system detected as debonding.

4.3/ Asphalt Thickness

By examining the peaks of the waveforms in the plots of Figure 4.1, it is clearly possible to identify the asphalt thickness. These measurements were made for the Papineau Creek data and are plotted in Figure 4.7. Comparing with the results obtained previously and given in Figure 4.8, we find good agreement. There is a small matter concerning the dielectric constant of the asphalt which is corrected in the new program and accounts for the discrepancy in the actual values previously obtained.

4.4/ Delamination Detection

The output from the delamination detector is plotted in Figure 4.9 for the DART system and compared with that produced by the HP 1000 in Figure 4.10. The new plot was produced by using high video whereas the old plot employed gated video. It is seen that the two plots do show general agreement in delamination detection, especially in the 29 to 32 m range, the 23 to 26 m range, and the 10 to 13 m range. In addition, agreement is good for areas with no delamination, such as the 14 to 20 m range.

We note that the new system has more hits in the areas of delamination than the old system but there are also more false indications. Part of the problem is thought due to the fact that the high video signal now being used was not originally intended for delamination detection and is a bit noisy as can be seen in the waveforms of Figure 4.1. This problem has been corrected in the new system by providing an interface buffer amplifier which feeds the proper level of high video to the analog-to-digital converter. Thus, the high video signals are now essentially noise-free, as will be seen in the following sections.

DEPTHS IN mm OVER 1m INTERVALS
****

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
37m	79	94	103	109	111	89	84	77	75	83	95	85	85	86	95	83	85
36m	76	82	111	108	103	96	94	88	83	86	88	84	81	88	83	80	98
35m	75	97	111	107	103	99	95	89	82	85	86	80	81	83	81	75	69
34m	70	105	111	107	104	99	98	91	79	84	83	81	79	78	78	77	67
33m	69	108	107	105	104	99	98	92	81	83	85	81	77	74	73	72	74
32m	75	104	105	104	98	92	92	85	79	86	87	83	78	75	72	72	82
31m	86	105	104	102	95	91	90	82	75	89	89	83	81	76	72	72	69
30m	66	99	98	96	94	91	93	86	76	88	87	87	84	77	74	72	65
29m	67	94	93	93	91	89	89	85	73	78	81	76	76	73	72	72	67
28m	66	92	91	92	87	85	84	80	72	78	77	75	75	72	71	70	66
27m	55	87	90	92	89	88	90	83	75	81	82	79	77	72	70	69	66
26m	54	84	85	87	87	85	87	85	80	86	89	84	78	72	71	69	83
25m	64	71	83	82	80	79	78	79	77	85	85	82	76	72	69	67	83
24m	77	83	76	79	75	74	73	81	82	94	87	83	77	69	69	67	82
23m	66	83	81	83	78	77	79	85	81	100	94	86	81	74	72	69	66
22m	64	84	83	83	82	82	80	83	79	96	96	90	85	75	73	68	65
21m	62	82	81	82	81	79	82	79	74	85	90	85	83	78	73	70	64
20m	57	83	82	82	78	77	79	75	74	82	83	81	81	78	74	76	64
19m	58	79	83	83	79	79	82	75	72	78	80	78	79	77	75	85	65
18m	63	79	82	78	78	76	76	75	69	78	76	75	75	73	69	87	61
17m	63	82	81	79	75	75	75	72	70	81	76	74	73	70	68	66	60
16m	75	78	79	75	75	73	73	72	69	76	77	72	71	69	66	68	61
15m	81	81	76	76	74	72	72	72	70	77	75	71	70	67	64	64	64
14m	77	84	82	85	78	78	78	75	72	80	75	73	73	70	68	69	61
13m	64	85	90	89	85	83	83	79	75	82	78	75	76	75	70	68	60
12m	58	94	107	108	105	93	86	82	78	83	90	85	82	84	89	84	101
11m	56	83	112	107	103	97	94	79	84	86	86	83	82	88	81	75	83
10m	59	102	110	107	104	100	96	81	79	85	85	79	79	79	80	74	69
9m	57	105	110	107	104	98	97	88	80	84	83	81	78	77	77	77	67
8m	73	108	107	105	103	98	98	86	81	83	86	82	79	74	72	71	89
7m	75	104	104	103	97	91	92	84	77	86	88	82	78	75	71	72	68
6m	74	104	102	101	95	91	89	82	75	89	88	85	82	76	73	71	67
5m	63	98	95	96	93	91	92	85	75	88	83	84	82	75	73	72	66
4m	63	93	92	92	90	88	88	77	72	78	78	75	76	73	72	71	67
3m	67	92	91	92	88	85	85	72	73	78	80	77	75	72	72	70	65
2m	70	86	87	92	88	88	89	75	77	81	83	81	77	72	69	68	66
LINE AVERAGE DEPTHS																	
	67	91	94	94	90	87	86	81	76	84	84	80	78	75	74	72	71

OVERALL DECK AVERAGE = 81

Figure 4.7/ Asphalt Thickness Printout for the DART System

#	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
37	84	102	114	118	118	97	90	83	81	91	101	89	91	94	101	83	92
36	82	91	119	116	111	103	101	94	89	93	94	89	86	95	88	87	107
35	82	105	113	115	111	106	103	96	88	91	92	85	86	88	87	80	78
34	75	114	119	116	112	107	105	96	84	89	89	86	84	84	83	82	72
33	74	115	116	114	111	107	107	98	86	89	91	86	83	80	79	77	79
32	83	112	113	112	106	99	99	91	84	92	93	88	83	80	77	78	90
31	88	112	111	109	102	97	97	89	81	95	94	89	86	82	78	77	74
30	71	106	105	103	101	97	100	93	83	93	97	92	90	82	79	77	71
29	72	101	100	98	96	95	96	91	77	83	85	83	82	78	77	77	71
28	72	99	98	98	94	91	91	85	79	83	84	81	81	77	76	75	71
27	59	94	97	98	96	94	98	89	81	86	88	85	86	78	76	74	70
26	57	90	91	91	92	91	91	91	81	93	97	90	84	76	77	74	85
25	70	78	68	86	86	82	84	85	84	92	98	88	82	76	73	72	92
24	82	88	83	85	82	79	79	87	87	99	94	90	83	75	73	73	80
23	70	89	87	88	86	83	83	91	88	108	102	92	87	80	79	75	71
22	69	90	88	89	88	87	86	88	83	103	102	96	90	82	78	74	70
21	66	88	86	86	87	84	86	84	81	92	95	89	88	84	79	76	69
20	61	90	88	88	84	83	85	81	80	88	86	85	85	84	79	83	70
19	63	85	89	87	86	84	86	80	76	84	85	84	85	83	80	89	69
18	70	84	88	84	83	81	82	80	74	83	82	80	80	77	75	88	66
17	65	87	86	85	81	80	80	76	74	86	83	80	79	75	73	70	64
16	83	85	84	81	81	79	79	77	74	83	82	77	76	74	71	74	67
15	86	85	84	83	80	79	79	77	76	84	88	76	75	72	69	70	69
14	83	91	83	91	85	85	85	81	79	85	82	79	80	76	73	74	65
13	67	98	96	95	93	91	90	86	81	87	85	81	84	81	76	81	60
12	61	86	95	95	91	89	92	86	84	91	89	86	88	86	79	67	54
11	60	84	92	90	87	85	86	85	85	91	90	89	90	86	78	66	53
10	63	81	91	92	90	89	89	87	88	97	97	94	94	92	84	72	54
9	63	81	93	92	92	91	95	93	91	102	106	103	105	103	81	76	63
8	82	87	91	92	91	90	95	92	92	113	115	111	112	115	68	78	77
7	82	88	90	90	91	91	94	90	93	113	115	112	112	108	94	85	76
6	74	97	93	94	92	92	94	88	93	114	115	112	117	115	98	82	75
5	67	90	97	97	94	89	91	90	88	101	108	100	111	116	79	83	79
4	69	108	99	96	92	88	86	83	80	91	99	98	104	80	77	79	80
3	72	110	102	94	90	85	83	78	75	87	95	96	100	111	74	81	76
2	77	96	92	88	91	86	92	76	71	82	85	87	89	91	82	86	68
1	***	***	96	95	***	76	***	71	66	76	91	85	86	90	115	86	83
0																	
AVE	72	93	96	95	93	90	90	86	82	92	93	90	89	86	79	78	73

OVERALL AVERAGE DEPTH = 86

Figure 4.8/ Asphalt Thickness Printout for the HP 1000 System

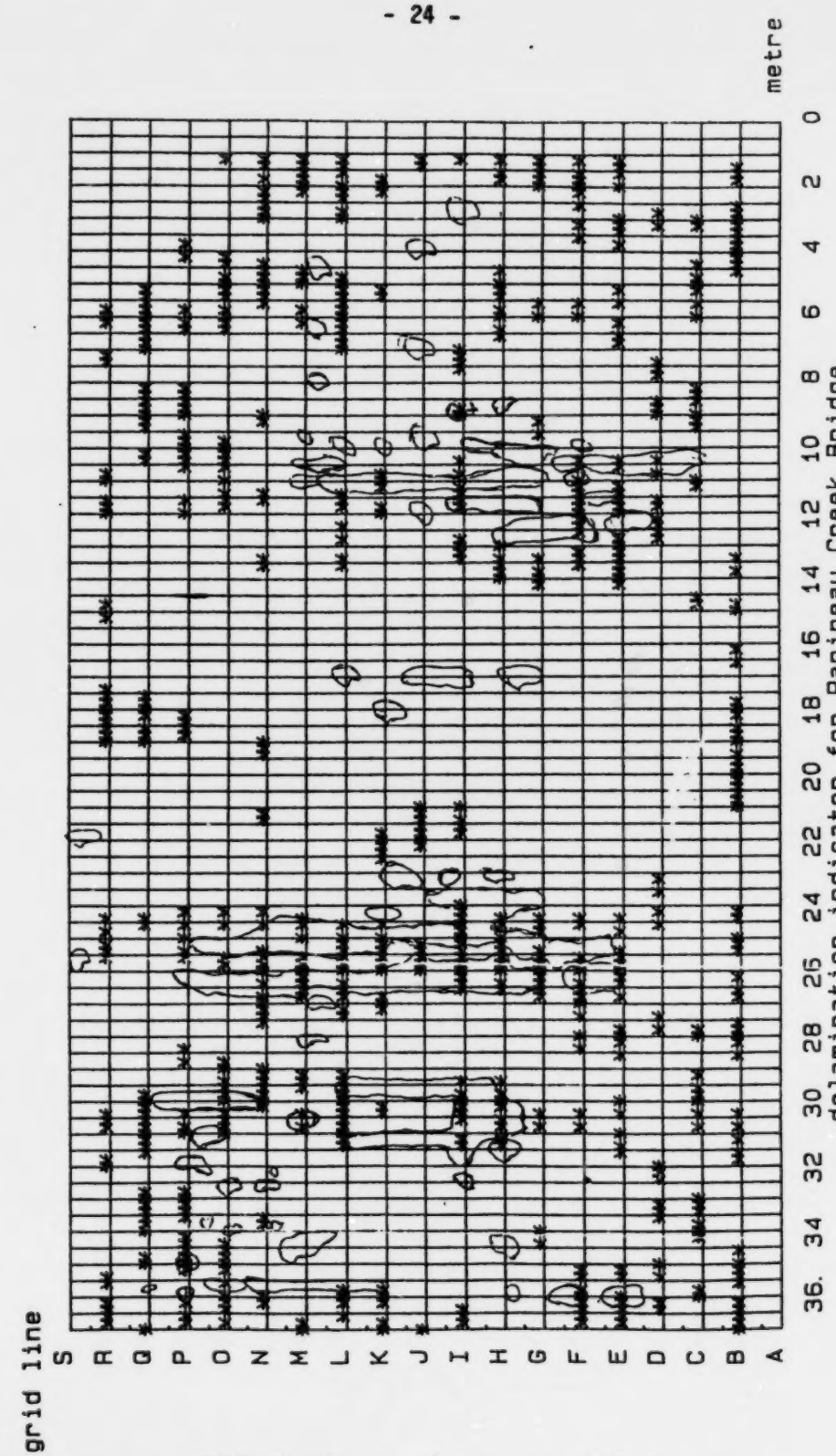

metre
0 2 4 6 8 10 12 14 16 18 20 22 24 25 28 30 32 34 36
delamination indicator for Papineau Creek Bridge
grid line
S R Q P O N M L K J I H G F E D C B A

Figure 4.9/ Delamination Plot for Papineau Creek Data Using the DART System (Note the actual delaminations sketched in the background.)

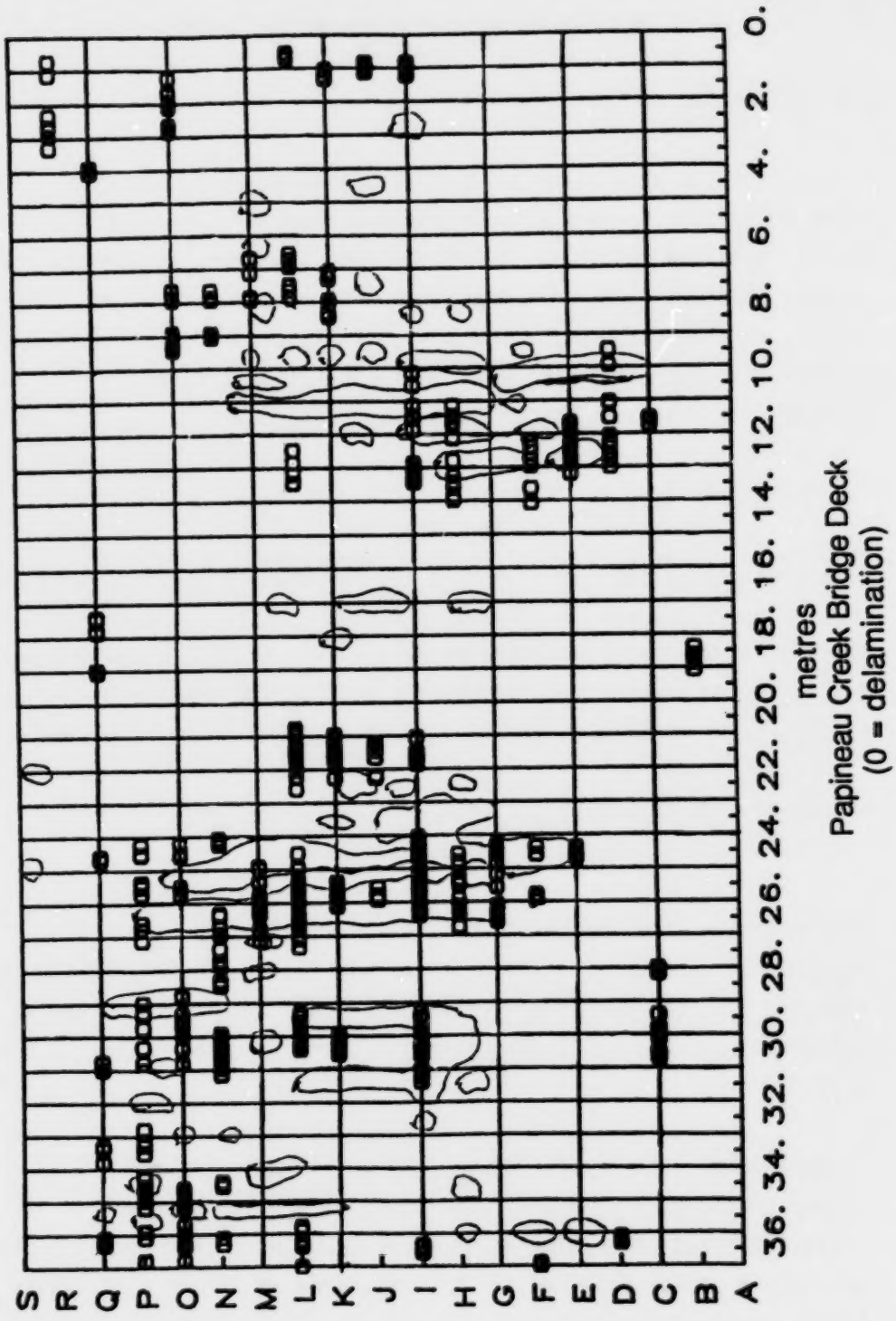


Figure 4.10/ Delamination Plot for Papineau Creek Data Using the HP 1000 System (Note the actual delaminations sketched in the background.)

5/ PROCESSING OF NITH RIVER BRIDGE DATA

5.1/ Collection of Data

A site visit to Nith River bridge, west of Kitchener, Ontario, on the McDonald-Cartier Freeway (Hwy 401) was conducted in mid-August of 1984 to collect data and test both the fifth wheel interface and the new tape recorder system. Six different lines were recorded with four lines in the travelled portion and two lines on the shoulder, as illustrated in Figure 5.1. The data were examined in the field and found to be suitably recorded for processing by the new DART system.

5.2/ Waveforms from the Nith River Bridge Deck

Sample waveforms for several lines are now presented and analysed.

The waveforms were gated into the DART system using the fifth wheel gating system which first reduces the data set in two ways:

- firstly, by inputting samples only when the fifth wheel signal is activated, and
- secondly, by effectively cutting this remaining data set in half by discarding the last 10 ms of each waveform.

For reference, the flat plate reflection is given in Figure 5.2. Here, we see that although the shape of the waveform is identical with that recorded for Papineau Creek bridge, the amplitude is considerably different. Hence, it is important to record the flat plate for each new site.

A small sample set of waveforms at 20 m intervals for lines 1, 3 and 6 is given in Figures 5.3 to 5.5. Included are one line in each of the travelled lanes and a line on the shoulder. Note that the waveforms are essentially noise-free, unlike the waveforms of Figure 4.1. These waveforms clearly demonstrate the flexibility of the system in providing detailed plots of signals.

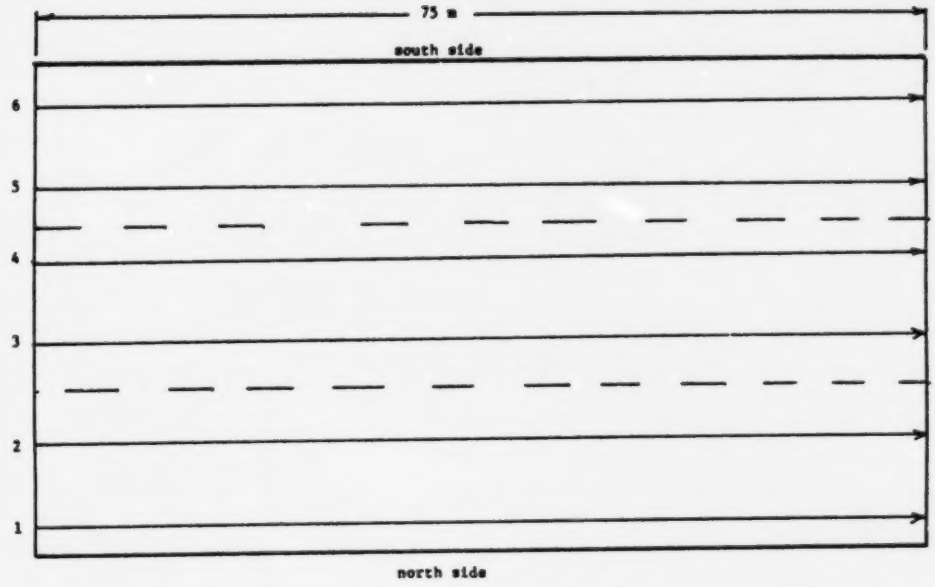


Figure 5.1/ Processing Lines for Nith River Bridge Deck, Westbound Section

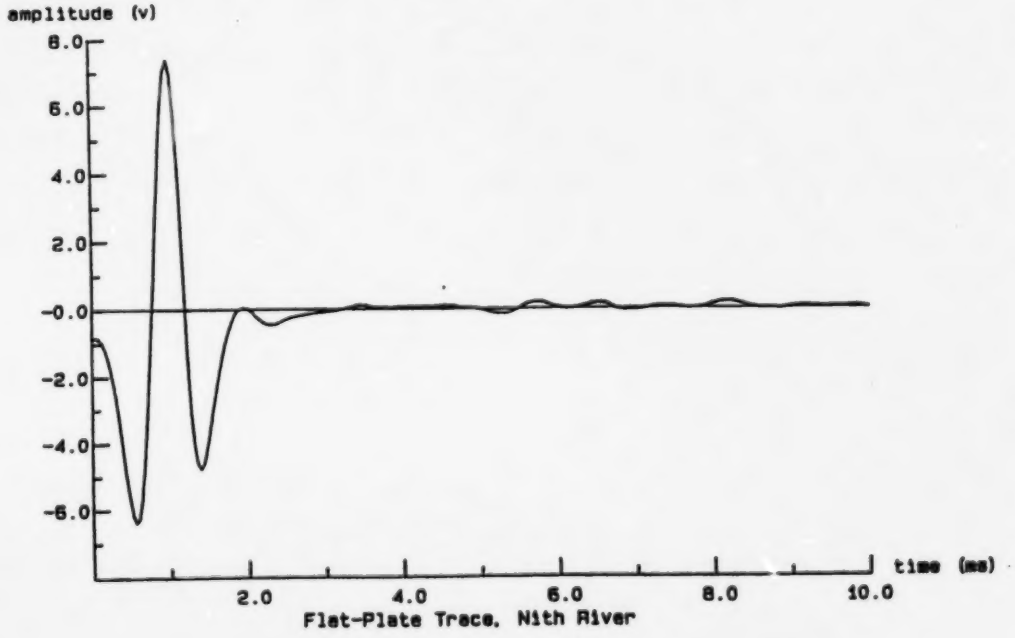


Figure 5.2/ Flat Plate Reflection for Nith River Data

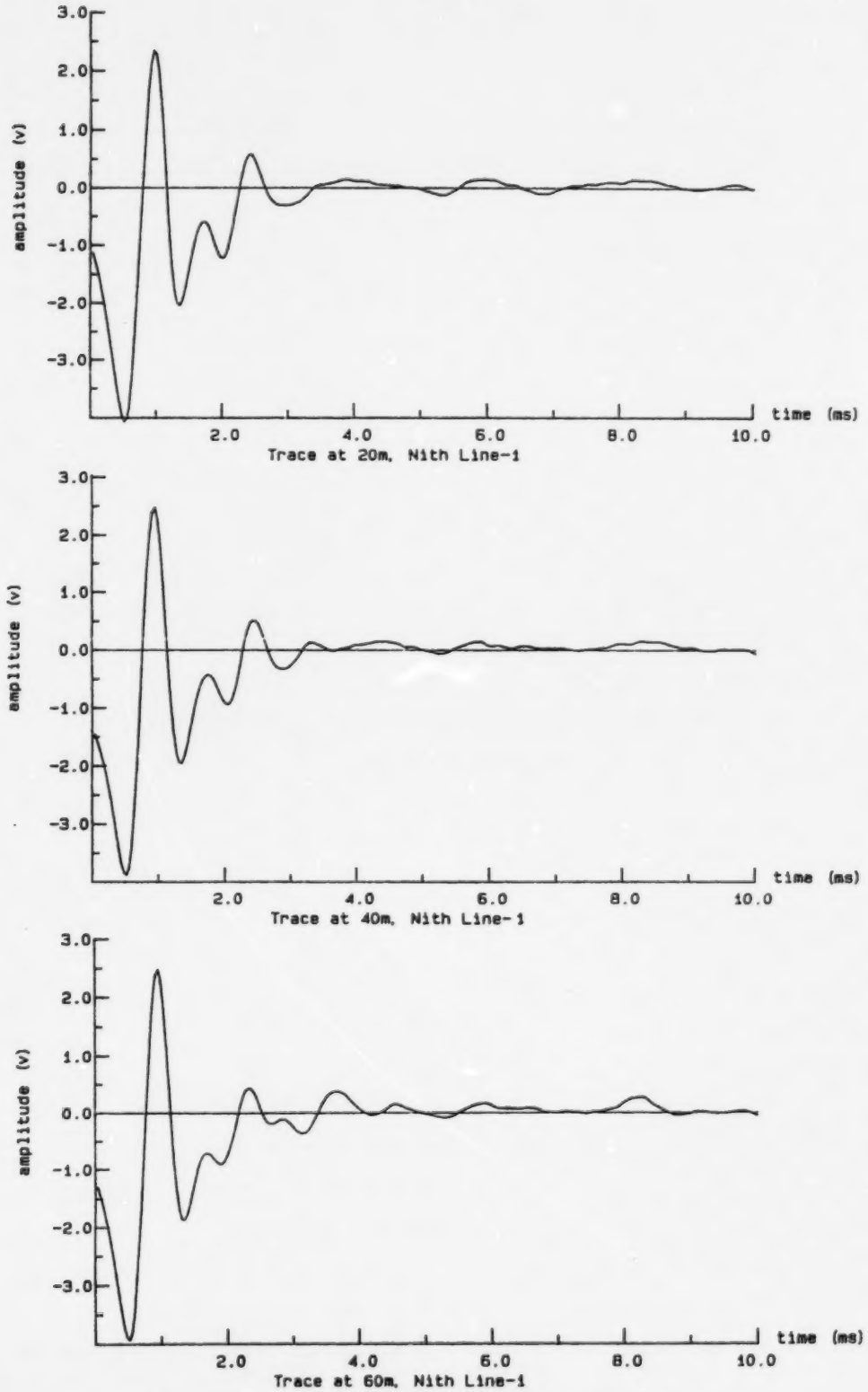


Figure 5.3/ High Video Waveform along Line 1
(Note the absence of rebar reflection.)

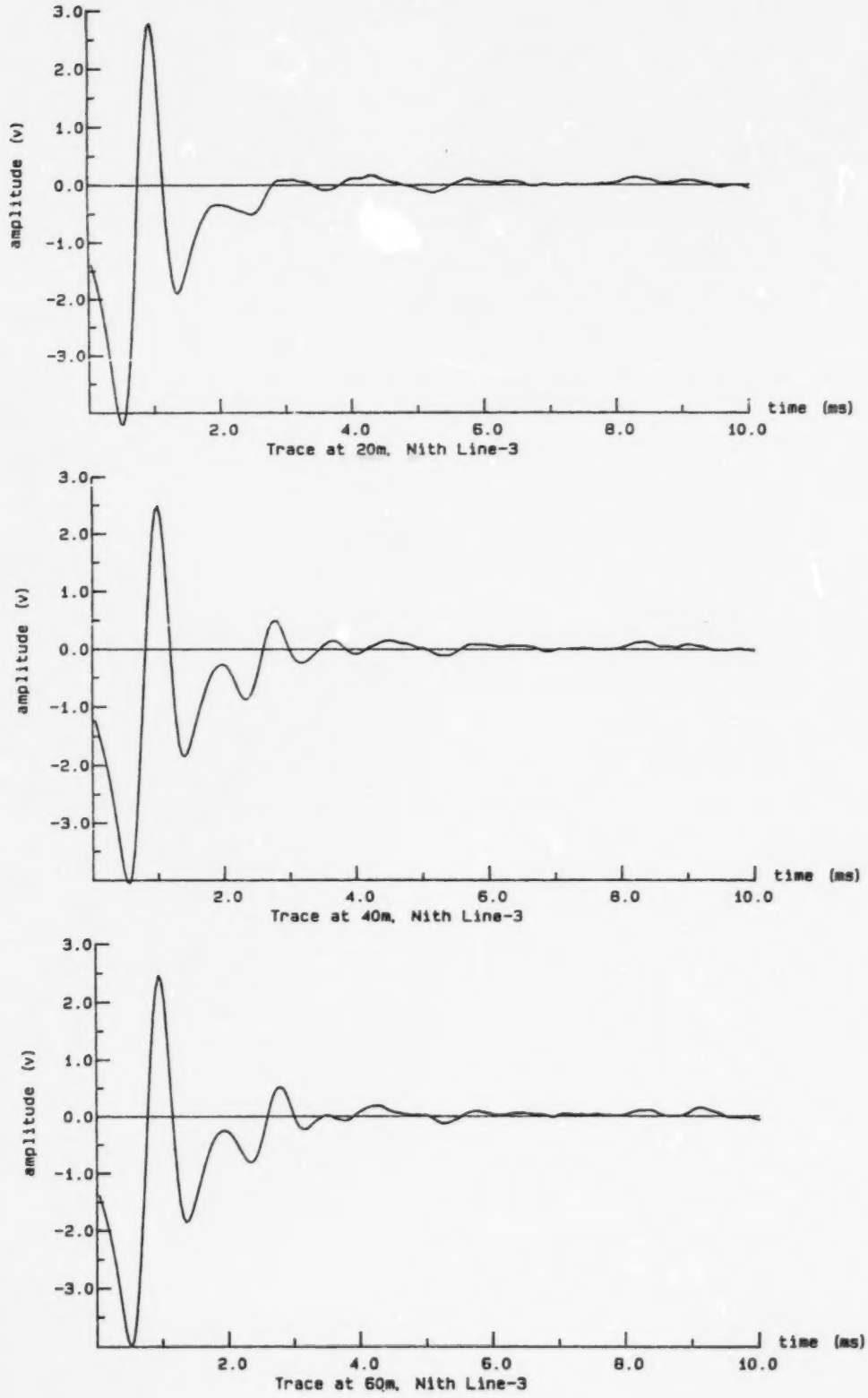


Figure 5.4/ High Video Waveform along Line 3

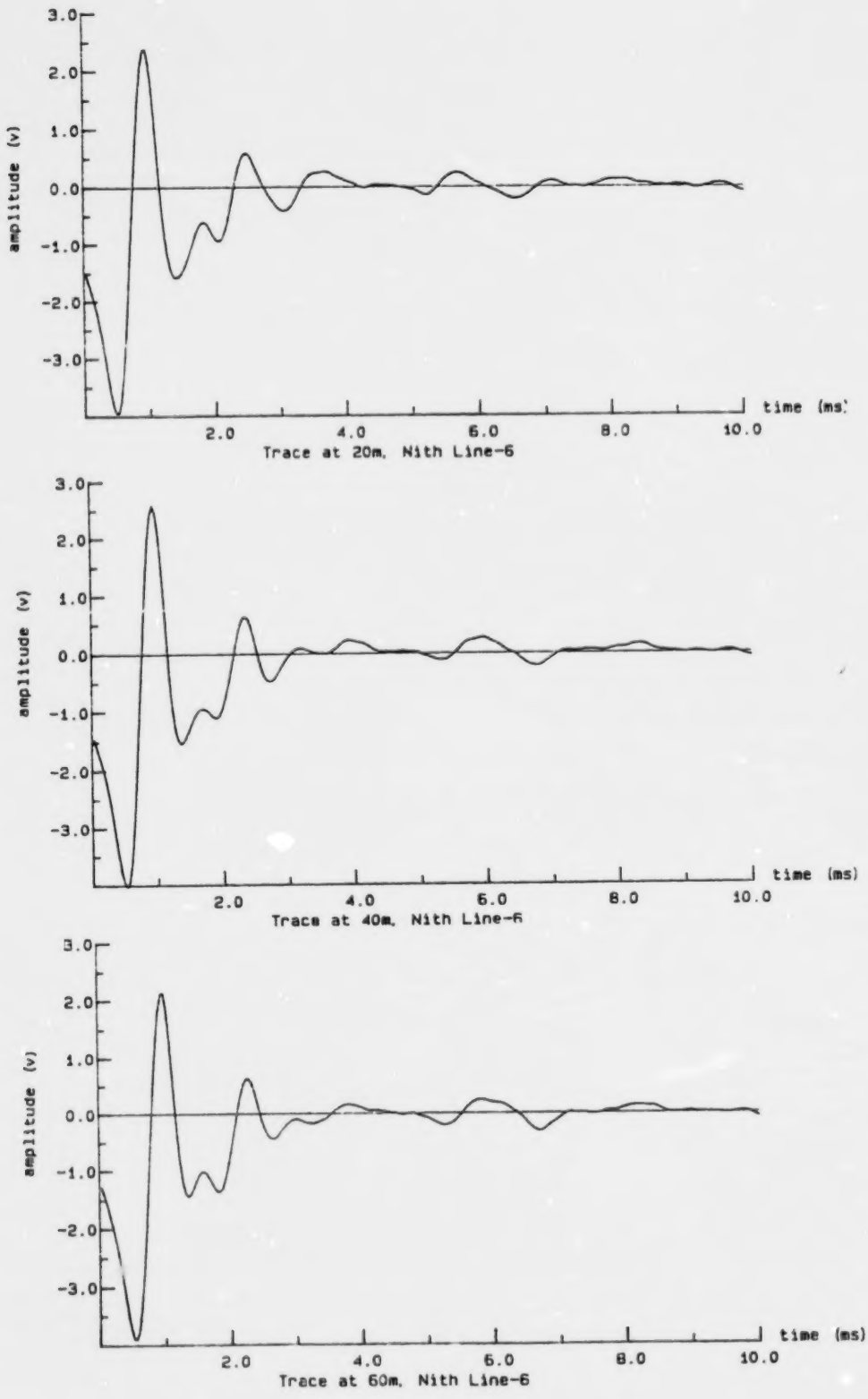


Figure 5.5/ High Video Waveform along Line 6

5.3/ Analysis of the Waveforms

In every case, we see that the surface reflection represented by the largest positive peak is well-defined and easily located. Since there is a protective membrane between the asphalt and the concrete, it is useful to determine the effects of this added feature. The material of the membrane is non-magnetic, consequently, there are only two possible effects:

- The dielectric constant will produce a certain reflection, dependent on the dielectric constant of the concrete and the asphalt.
- A loss may take place when the wave passes through the membrane.

The first effect appears to be minimal since the dielectric constant of the membrane and that of asphalt are not very different. Thus, no significant reflection is seen to result from the wave impinging on the membrane.

The second effect is less certain. Since there is a significant amount of waveform reflected from the membrane-concrete interface, it can be concluded that the loss in passing through the membrane is also negligible. However, we note that in many traces, the waveform following the asphalt-concrete interface is reduced considerably from what might be expected. Consequently, no direct information concerning the membrane can be obtained by examining the waveforms for separate reflections. However, some indirect information is available. We note that the membrane increases the distance between the asphalt surface and the asphalt-concrete interface.

Another observation which is apparent is the poor definition of the reflection from the rebars. Only in a few cases is it possible to find well-defined reflections in the expected locations. This may be due to several different possible causes. Firstly, there may be wide-scale delaminations on the deck which would account for the distorted waveforms. Secondly, the rebars may be badly rusted or corroded, which would greatly reduce the reflection of the incident wave. Thirdly, the loss in passing through the membrane may cause the reflection from the rebars to be masked. In any case, the waveforms indicate that there is a problem with the rebar reflection.

5.4/ Asphalt Thickness

As noted in Section 5.2, both the peak from the surface and the asphalt-concrete interface are well defined. Since the dielectric constant of every footprint is calculated, the asphalt depth is easily measured and is printed in Figure 5.6. Comparing the measured values with those taken from core samples on lines 4 and 6 (Figure 5.7), we see that agreement is reasonably good with the average depth of the measured, and cored, being 125 mm and 106 mm, respectively, for line 4, and 105 mm and 91 mm, respectively, for line 6. Thus, there appears to be a consistent error of approximately 15 to 20%.

This error can partially be explained by noting that the dielectric constant used is determined by measuring the reflection from the asphalt surface. If the dielectric constant beneath the surface is, in fact, higher (which is certainly reasonable), then the asphalt thickness calculation would always be too high. Other than noting this as an empirical relation, there appears to be no simple way of providing a more accurate correction. Hence, the overall measured asphalt depth of 116 m would correspond to an actual depth of approximately 100 mm.

5.5/ Debonding, Scaling and R1/R2 Ratios

Debonding and scaling are detected by noting the relationship between the amplitude of the reflection from the asphalt-concrete interface in relation to the surface reflection. These R1/R2 plots are provided in Figure 5.8 for the six lines of Nith River bridge data.

The plot for debonding, given Figure 5.9 with the threshold settings used for Papineau Creek data, indicates that the deck is badly debonded. This requires the proper interpretation, however, since the Nith bridge deck (unlike Papineau Creek) includes a membrane. Thus, a second interpretation which may apply to bridge decks with the membrane is that the R2 ratio gives a measure of the condition of the membrane. In this case, the variability of the R2 ratio indicates that perhaps the membrane has been crushed in some area (particularly in the driving lanes) and the remaining waveforms are normal. Another interpretation is that the membrane is tightly sealed in the driving lane and loosely sealed in the curb lane.

DEPTHS IN mm OVER 1m INTERVALS

	1	2	3	4	5	6
1m	121	114	120	126	134	196
2m	111	104	110	113	108	160
3m	111	111	105	109	99	202
4m	109	103	105	105	97	143
5m	111	94	106	113	102	104
6m	113	95	108	113	110	98
7m	114	104	109	120	103	86
8m	108	109	119	123	107	91
9m	115	110	125	127	125	98
10m	116	113	123	126	127	110
11m	117	119	126	122	116	109
12m	114	121	126	128	115	107
13m	113	120	128	122	119	93
14m	113	119	131	128	123	94
15m	109	120	128	130	103	96
16m	100	115	131	129	109	99
17m	98	105	131	121	106	97
18m	99	103	123	128	107	106
19m	96	105	120	119	113	142
20m	108	115	137	135	127	117
21m	108	114	135	130	116	112
22m	104	110	127	132	107	109
23m	103	112	129	130	107	104
24m	105	110	124	125	106	92
25m	102	108	124	121	107	96
26m	96	112	125	124	112	102
27m	95	111	128	124	114	105
28m	101	117	127	119	123	101
29m	106	115	137	123	111	104
30m	104	116	134	121	110	102
31m	113	115	124	117	110	102
32m	120	112	126	118	117	96
33m	118	114	126	123	117	107
34m	109	113	122	126	120	106
35m	118	118	117	121	119	109
36m	117	129	118	122	117	103
37m	121	133	122	127	116	99
38m	114	127	125	126	126	94
39m	115	116	132	126	123	97
40m	114	107	129	123	127	99
41m	112	109	134	129	118	99
42m	112	103	136	139	118	101
43m	107	112	147	142	122	104
44m	113	112	146	144	122	101
45m	122	110	140	144	118	101
46m	114	112	140	129	119	102
47m	113	113	132	125	116	103
48m	107	118	127	125	119	101
49m	101	121	124	128	122	93
50m	111	115	123	132	130	96
51m	105	116	129	129	124	103
52m	106	121	122	126	122	102
53m	108	112	129	129	128	105
54m	105	118	127	131	123	109
55m	104	126	125	128	122	99
56m	102	121	129	125	117	99
57m	110	123	131	129	119	109
58m	113	119	142	124	123	113
59m	102	117	138	133	123	110
60m	101	119	136	131	125	107
61m	108	127	133	127	126	106
62m	110	129	135	130	118	107
63m	107	129	132	130	117	110
64m	111	113	126	134	119	112
65m	118	119	117	137	120	107
66m	115	123	115	129	111	97
67m	111	130	116	126	114	92
68m	111	122	122	126	111	90
69m	114	118	124	122	108	89
70m	103	122	132	125	109	89
71m	110	117	126	118	108	94
72m	116	119	118	115	106	90
73m	116	121	118	106	104	90
74m	111	109	102	93	94	91
75m	103	109	94	91	100	89

AVERAGE LINE DEPTHS

1	2	3	4	5	6
109	115	125	125	115	105

OVERALL DECK AVERAGE = 116 mm

Figure 5.6/ Radar Measured Asphalt Depth

NITH RIVER BRIDGE, ASPHALT THICKNESS*

Line	Grid Point	Thickness (mm)
4	10	105
4	20	110
4	25	100
4	30	100
4	40	115
4	50	105
4	60	105
6	10	90
6	15	90
6	25	90
6	30	90
6	35	95
6	45	95
6	55	95
6	65	85

* Note: Many of the cores broke through the asphalt, with the result that the thickness reported should be considered accurate to within ± 5 mm.

Figure 5.7/ Thickness of Asphalt (Including Waterproofing Membrane) as Measured from Core Samples Taken on Nith River Bridge

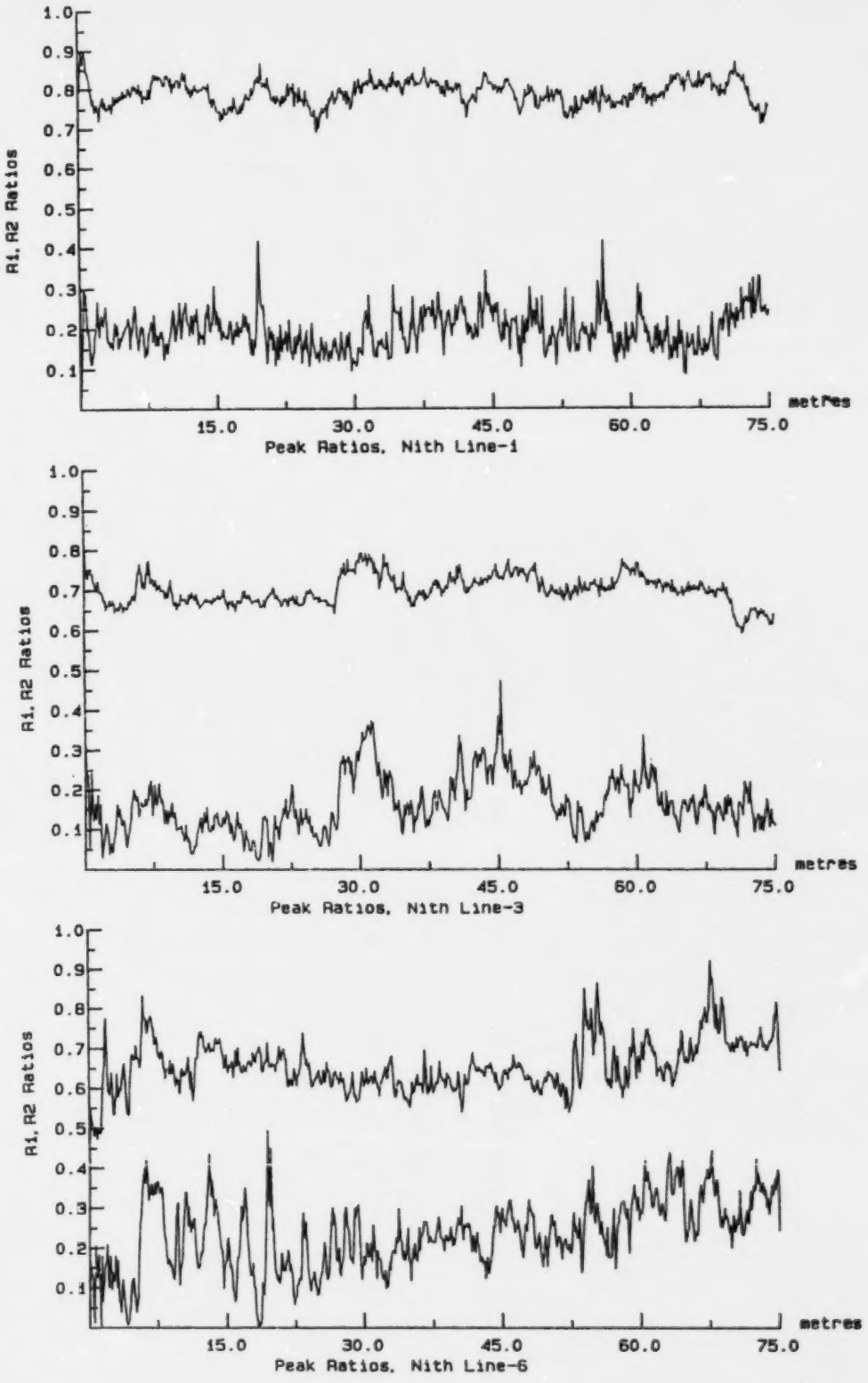


Figure 5.8/ R1/R2 Ratios for Nith River Bridge

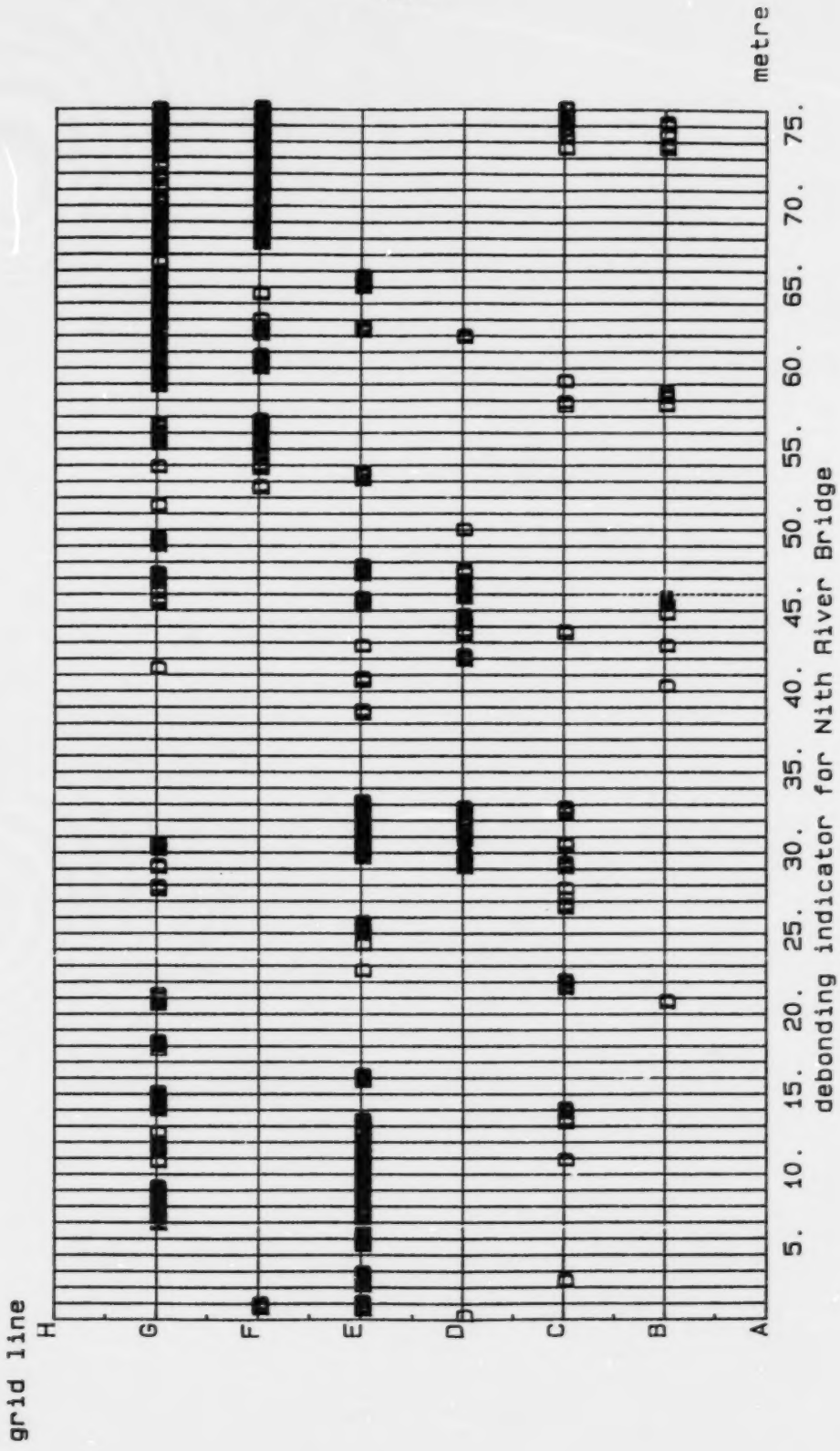


Figure 5.9/ Debonding Plot for Nith River Bridge Using the DART System

Figure 5.10 gives the plot for scaling. We see there is very little scaling on the Nith River bridge deck since the R1/R2 ratios are well below the threshold values in most locations.

5.6/ Delamination

Detection of delamination is the most difficult since the waveform to be analysed is furthest in time from the beginning. This leads to possible errors due to second-time-around reflections and losses in the other layers. The waveforms have been examined in detail to determine whether the expected "characteristic W" is present. In many cases, the waveform is seen to exist, but in other cases, the reflection from the rebars is weak or almost non-existent.

The output from the delamination detector measures the number of slope changes in the waveform between the asphalt-concrete interface and the rebars. These outputs are given in the plot of Figure 5.11. We see that the results indicate Nith River bridge deck has considerable delamination damage, especially along the travelled portion of the deck (lines 1, 2 and 3).

Thus, the overall assessment of Nith River bridge using radar data is that there may be a problem with the membrane and there may be a significant number of delaminations. However, there is essentially no scaling and no debonding.

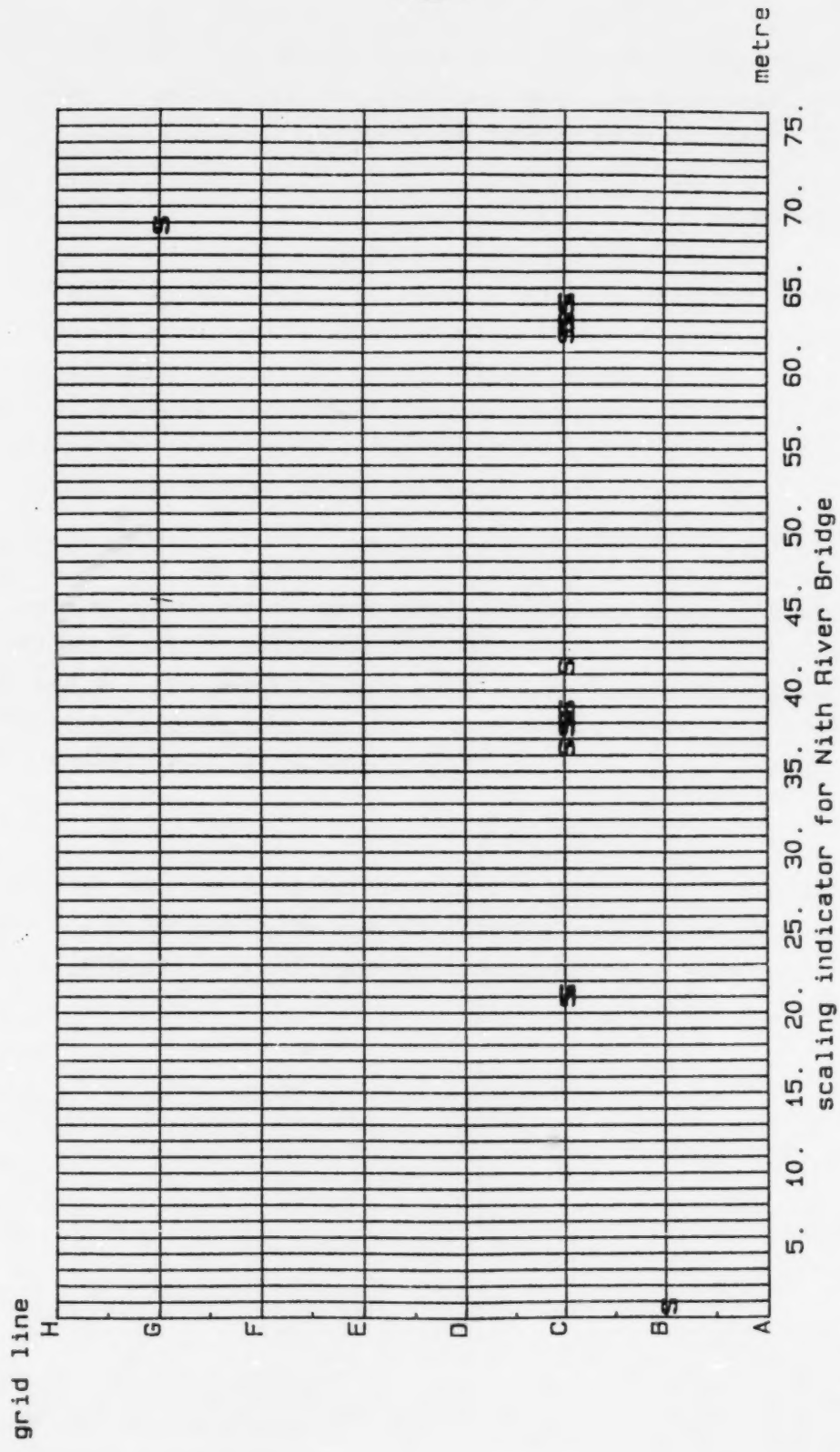


Figure 5.10/ Scaling Plot for Nith River Bridge Using the DART System

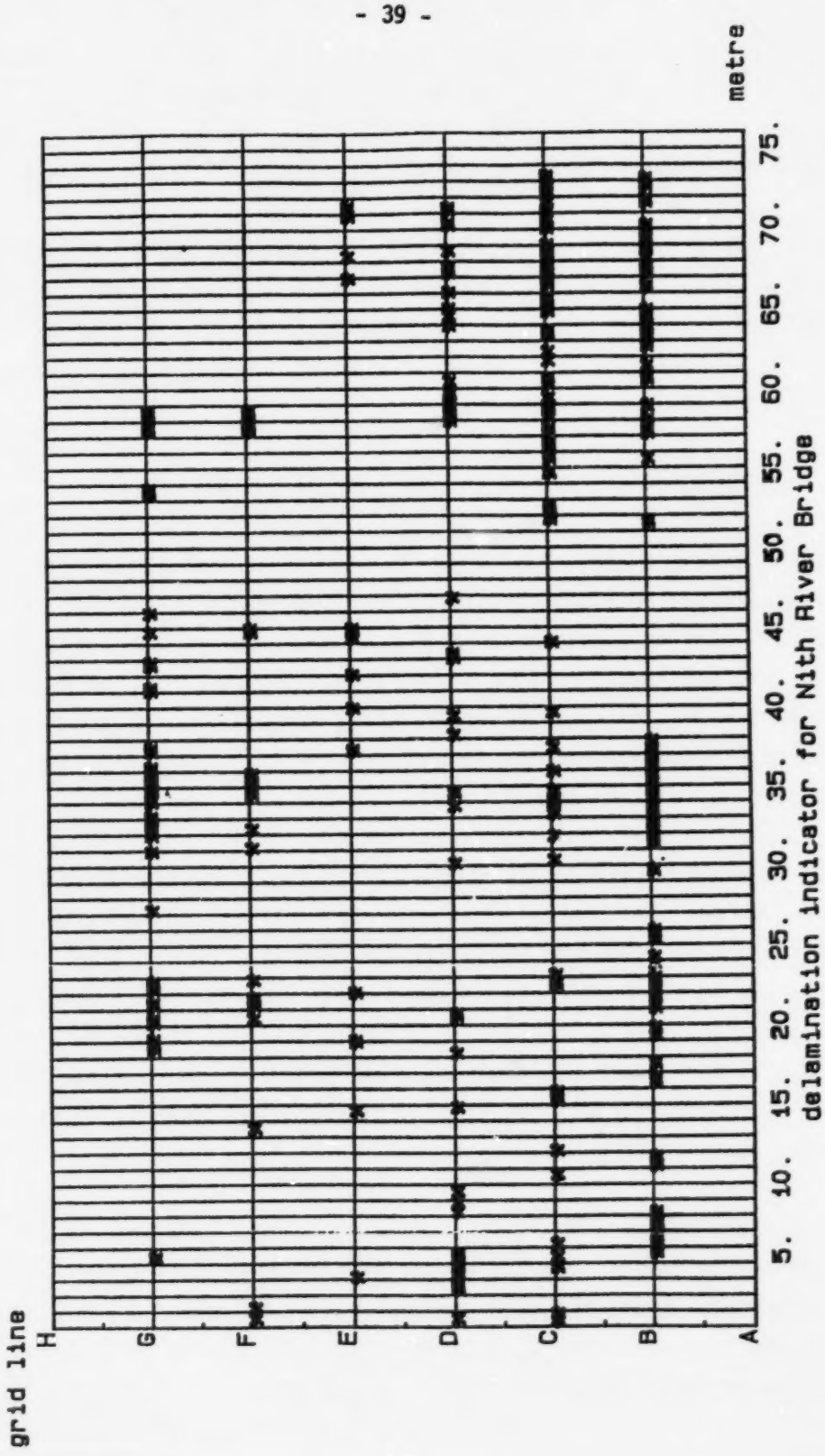


Figure 5.11/ Delamination Plot for Nith River Bridge Using DART System

6/ PROCESSING OF CPR OVERHEAD DATA

6.1/ Collection of Data

Data for the CPR Overhead, located west of Kitchener on the McDonald-Cartier Freeway (Hwy 401) were collected in late August, 1984, using the the new system. Seven different lines were recorded with four of the lines in the travelled portion of the highway and three lines on the shoulder, as shown in Figure 6.1.

6.2/ Waveforms from CPR Overhead and Detailed Analysis

The flat plate measurement is given in Figure 6.2 and sample waveforms from the CPR Overhead are illustrated in Figures 6.3 to 6.5 for lines 1, 3 and 7. This includes one line in each of the travelled lanes and a line on the shoulder. It is noteworthy that the amplitude of the flat plate measurement is again considerably different from the previous two bridge deck measurements. We further note that the surface reflection is again well defined for all plots.

Of considerable importance is the fact that the reflection from the asphalt-concrete interface is not only well defined, but also much further along in time from the previously measured bridge decks. An examination of the dielectric constant shows in this case a value of the order of approximately 7. This is in sharp contrast to the earlier values of 3 to 4 found for Papineau Creek and Nith River bridge data. Hence, the importance of computing the dielectric constant for every measurement is clearly established.

Another significant factor is that the propagation speed of the wave in the asphalt is inversely proportional to the square root of the dielectric constant. Thus, the gates which are used to identify parts of the traces can be automatically adjusted to take account of the differing values by using the measured dielectric constant.

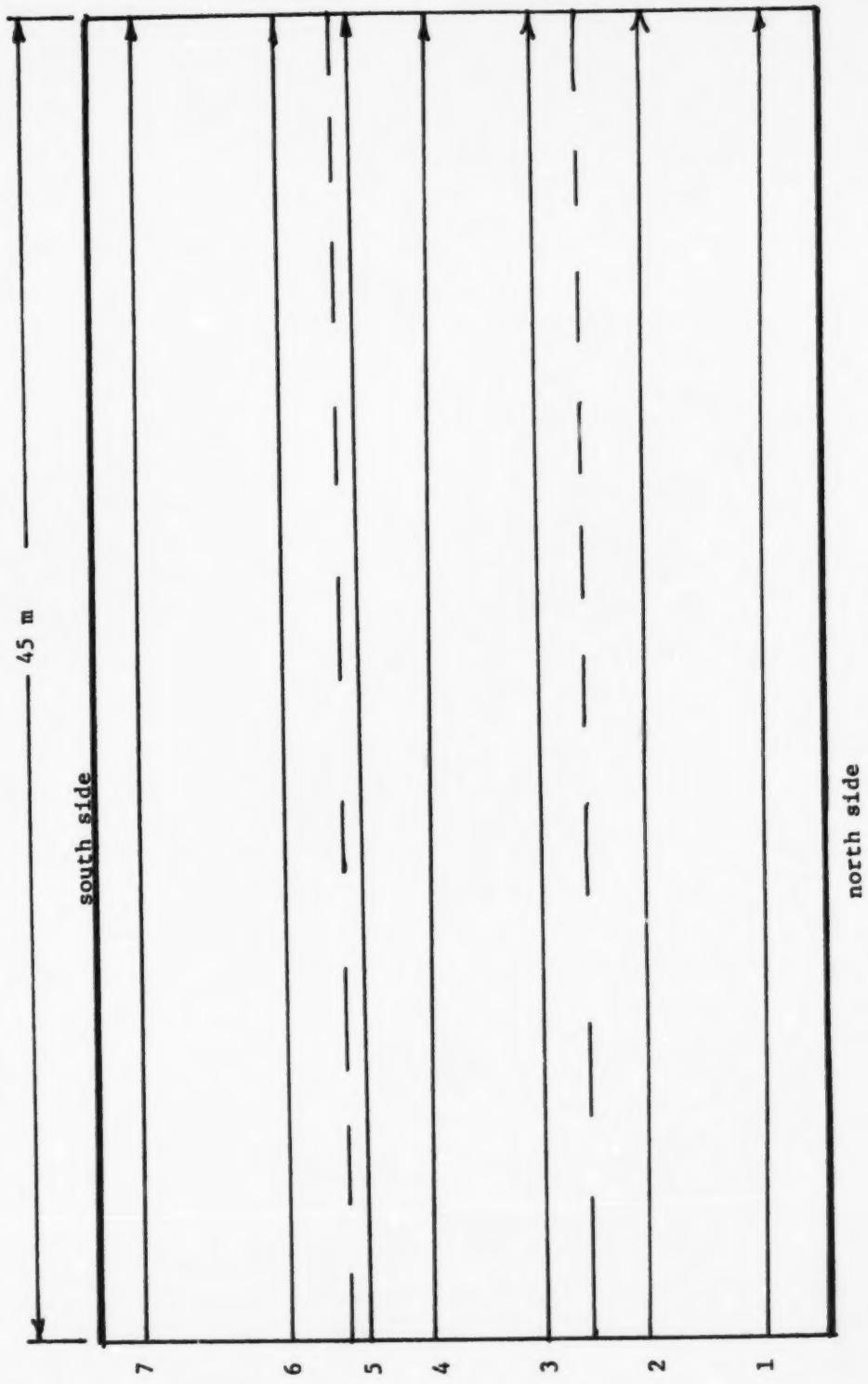


Figure 6.1/ Processing Lines for CPR Overhead, Westbound Section

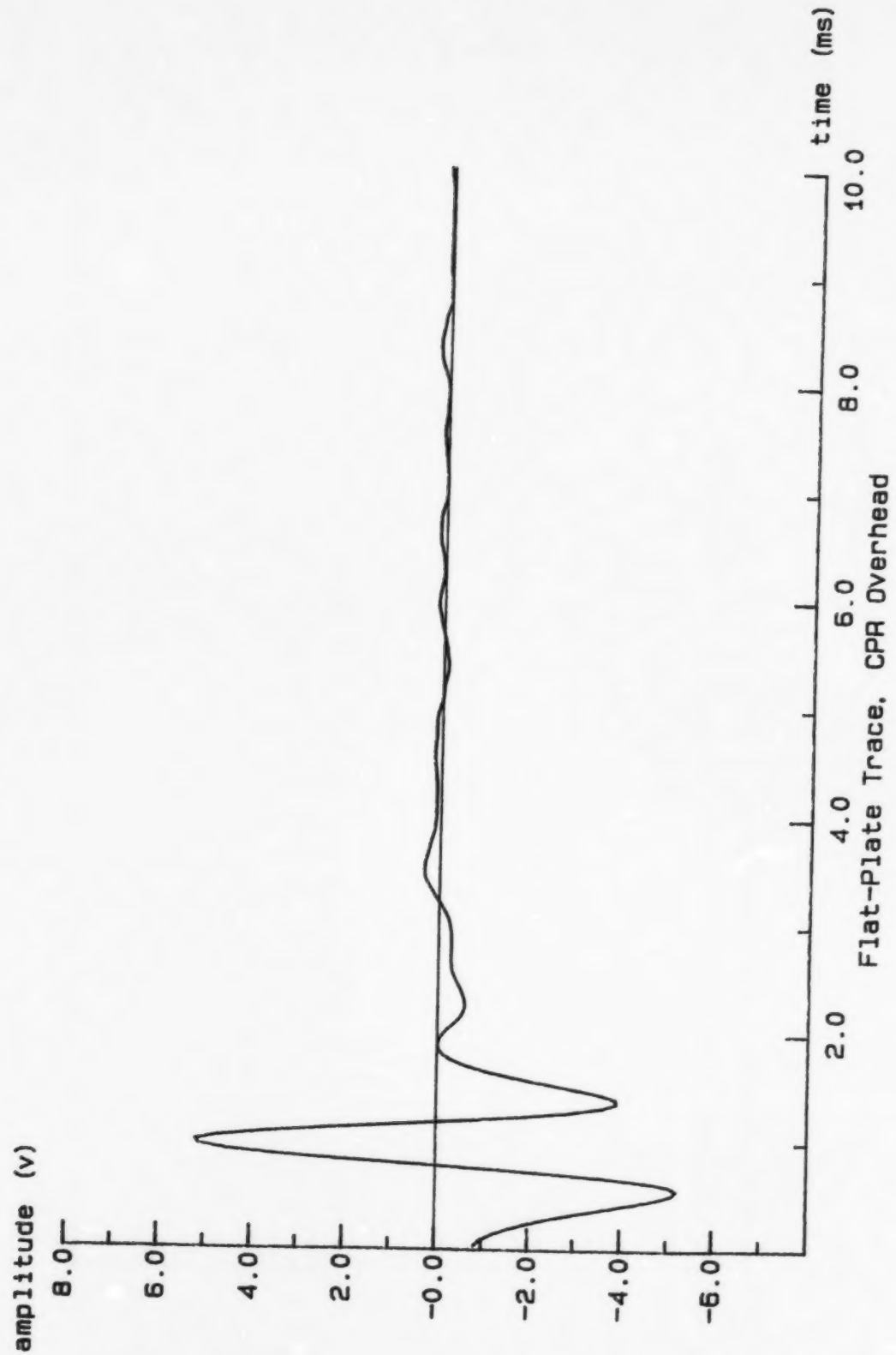


Figure 6.2/ Flat Plate Reflection for CPR Overhead Data

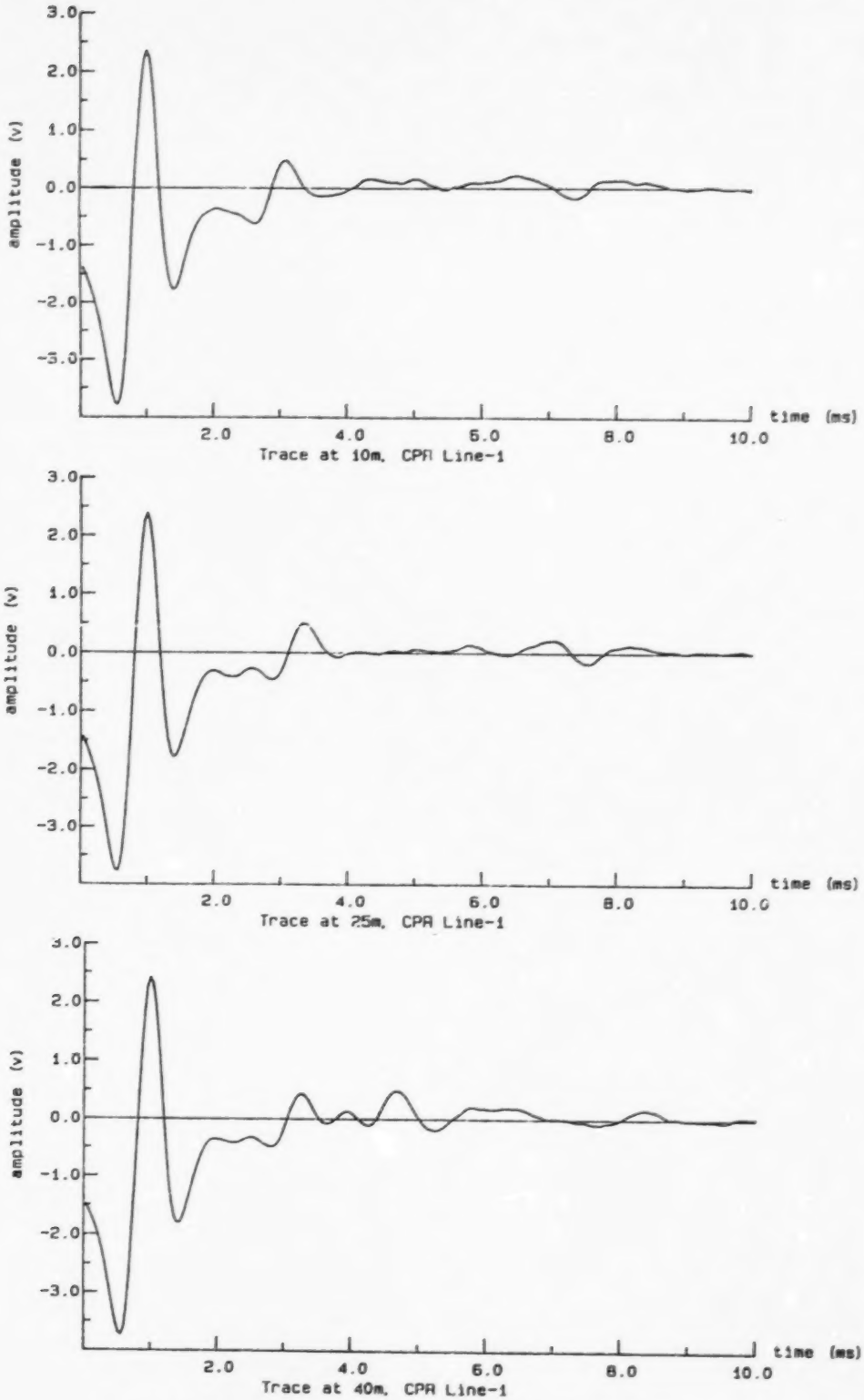


Figure 6.3/ High Video Waveform along Line 1
(Note the absence of rebar reflection.)

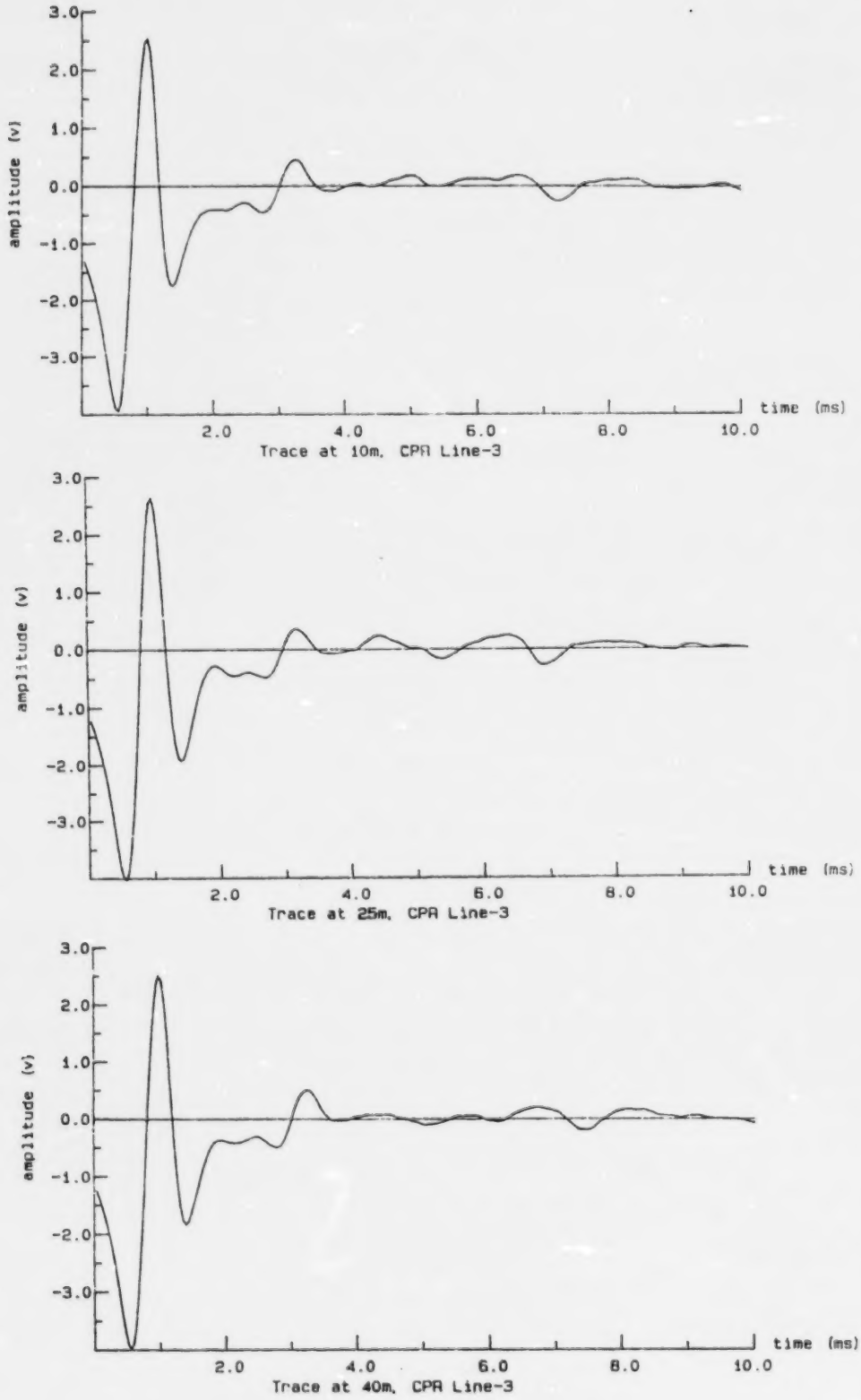


Figure 6.4/ High Video Waveform along Line 3

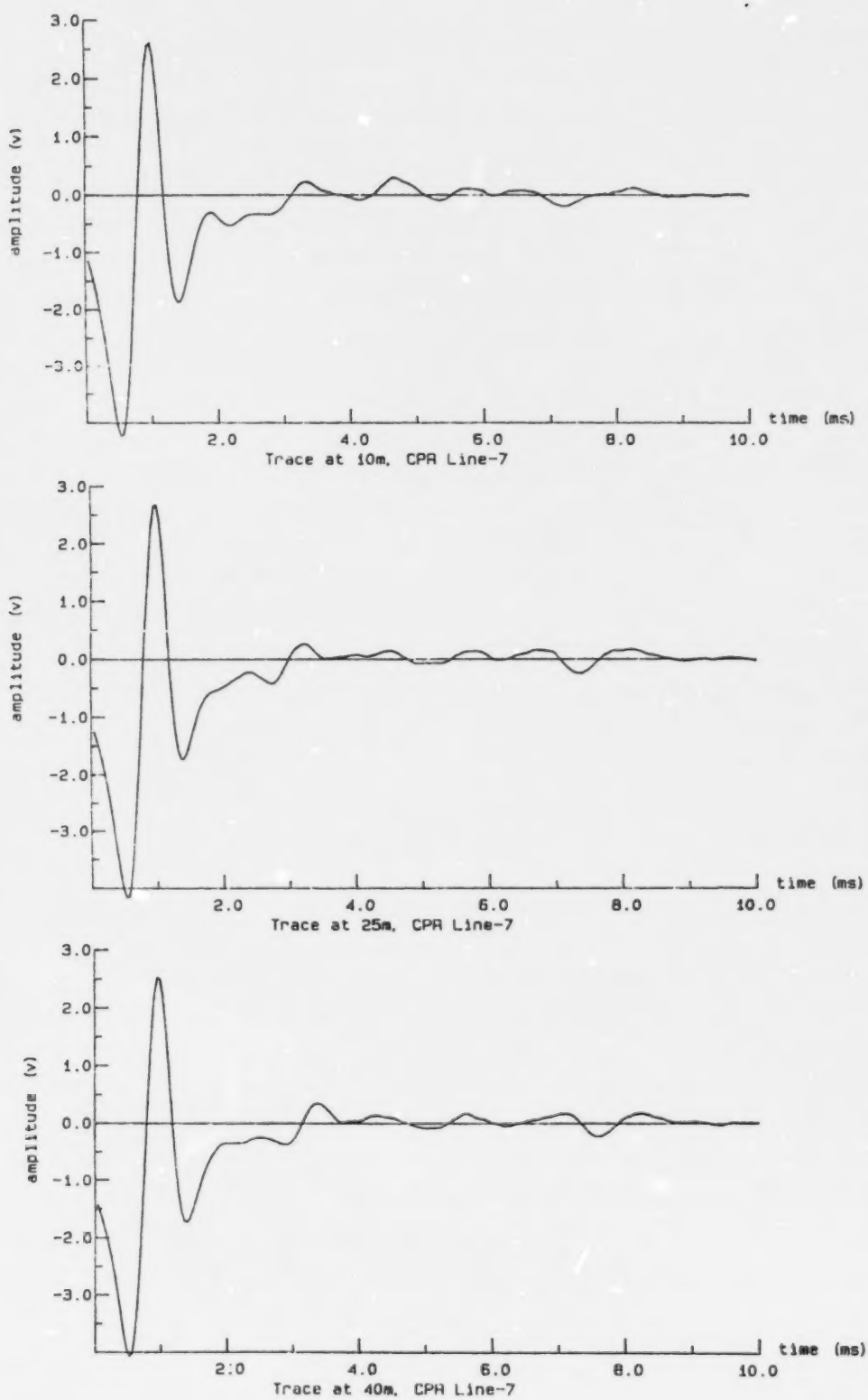


Figure 6.5/ High Video Waveform along Line 7

6.3/ Asphalt Thickness

Again, the asphalt thickness was measured by computing the time delay between the surface reflection peak and the asphalt-concrete interface peak and this is plotted in Figure 6.6. We see that the average thickness is approximately 121 mm, which is 5 mm more than the value obtained at Nith river bridge. One core sample taken at the 24 m point on line 1 indicated an asphalt thickness between 125 and 130 mm. This compares very well with the radar determination of 128 mm.

6.4/ Debonding, Scaling and R1/R2 Ratios

The R1/R2 ratios for lines 1, 3 and 7 are plotted in Figure 6.7. For almost all lines, the R1 ratio is below the threshold, indicating that scaling is not present. The R2 ratio is also well behaved, indicating that debonding is not a problem and the membrane is in good condition.

The plot from the debonding detector is given in Figure 6.8. Aside from a few random indications, there appears to be no problem due to debonding or the membrane. Figure 6.9 gives the plot for the scaling detector, which shows essentially no scaling.

6.5/ Delamination

Using the same strategy here as employed for Nith river data, the delamination detector output was calculated and is presented in the plot of Figure 6.10. We see that there are a few random indications of delamination but the number is far less than for the other two bridge decks.

Thus, we conclude that the CPR Overpass is in relatively good shape with no problems due to debonding or scaling, no problem with the membrane, and little or no delamination damage.

DEPTHS IN mm OVER 1m INTERVALS
****

	1	2	3	4	5	6	7
1m	106	123	130	127	132	141	139
2m	111	115	111	119	121	107	124
3m	116	117	105	121	126	104	118
4m	112	128	113	124	126	113	110
5m	113	129	123	127	129	117	104
6m	115	121	123	127	129	118	105
7m	123	113	124	130	131	120	107
8m	125	121	121	136	131	115	110
9m	122	126	124	136	123	115	113
10m	118	126	117	136	117	110	114
11m	115	123	120	127	110	112	109
12m	116	122	120	135	115	117	103
13m	115	111	120	143	119	118	109
14m	111	111	118	142	122	119	109
15m	121	112	119	134	121	117	112
16m	126	117	117	132	119	121	119
17m	124	115	110	135	123	127	115
18m	131	110	108	137	133	121	115
19m	136	120	108	129	142	127	112
20m	133	132	108	125	134	133	114
21m	128	132	115	131	127	123	119
22m	126	124	116	130	123	122	123
23m	131	121	108	132	132	111	115
24m	128	128	106	131	131	109	114
25m	125	129	108	134	125	122	111
26m	131	132	106	131	129	117	105
27m	129	127	108	130	135	113	111
28m	127	125	116	136	134	124	112
29m	122	119	116	133	138	124	108
30m	122	116	118	137	134	125	111
31m	121	118	120	138	123	125	111
32m	119	112	122	133	122	120	116
33m	120	113	125	133	119	113	116
34m	120	114	120	132	120	111	112
35m	116	121	118	131	115	109	107
36m	127	123	117	129	110	110	100
37m	127	119	115	131	115	110	108
38m	125	128	114	130	122	115	114
39m	122	123	118	130	130	121	117
40m	124	114	115	129	125	124	121
41m	121	116	120	124	116	124	121
42m	117	126	115	121	113	127	120
43m	122	116	118	121	111	116	120
44m	124	112	122	126	114	115	118
45m	121	111	124	136	119	117	111

AVERAGE LINE DEPTHS

122	120	116	131	124	118	113

OVERALL DECK AVERAGE = 121

Figure 6.6/ Radar Measured Asphalt Depth

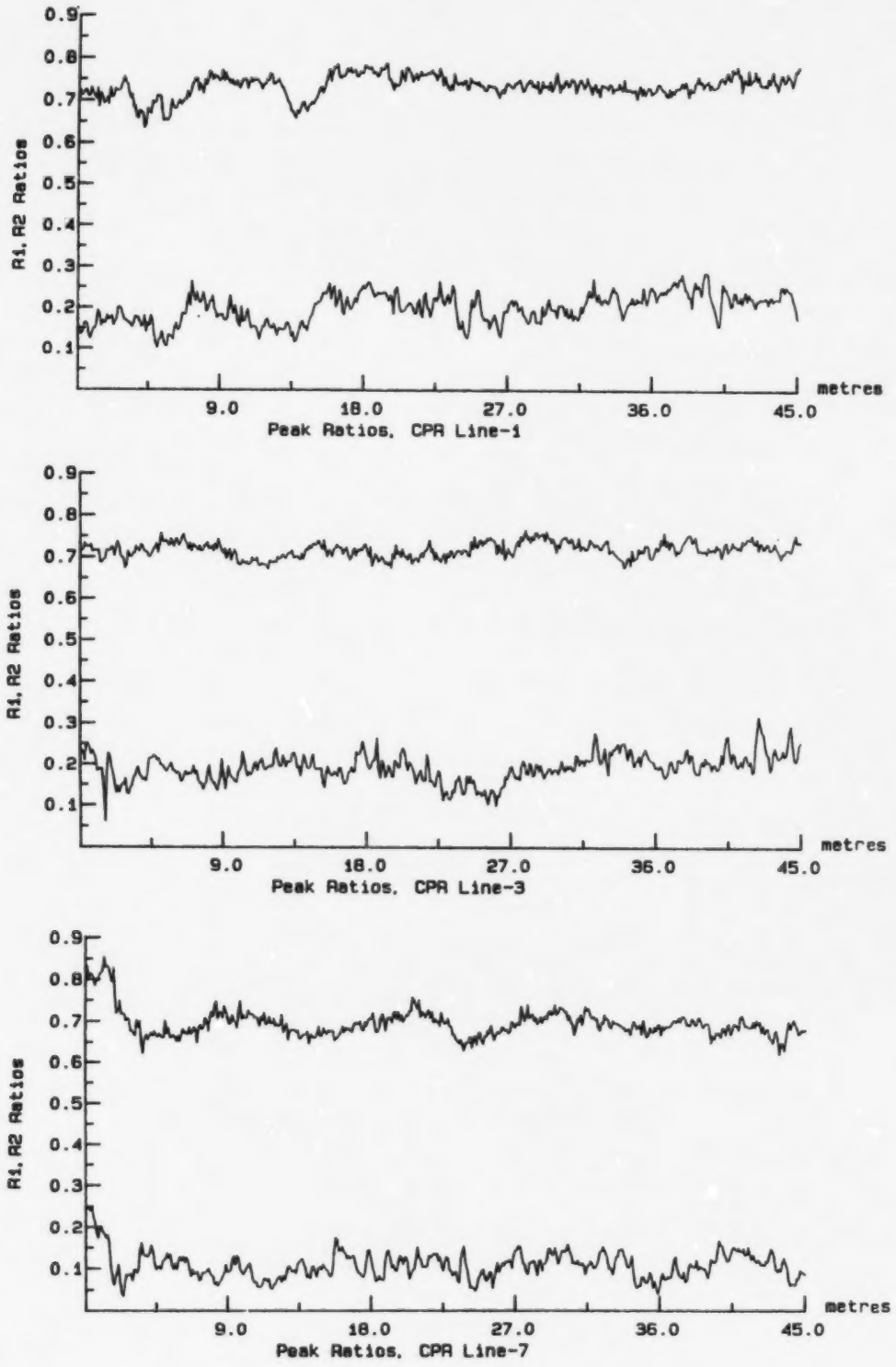


Figure 6.7/ R1/R2 Ratios for CPR Overhead Data

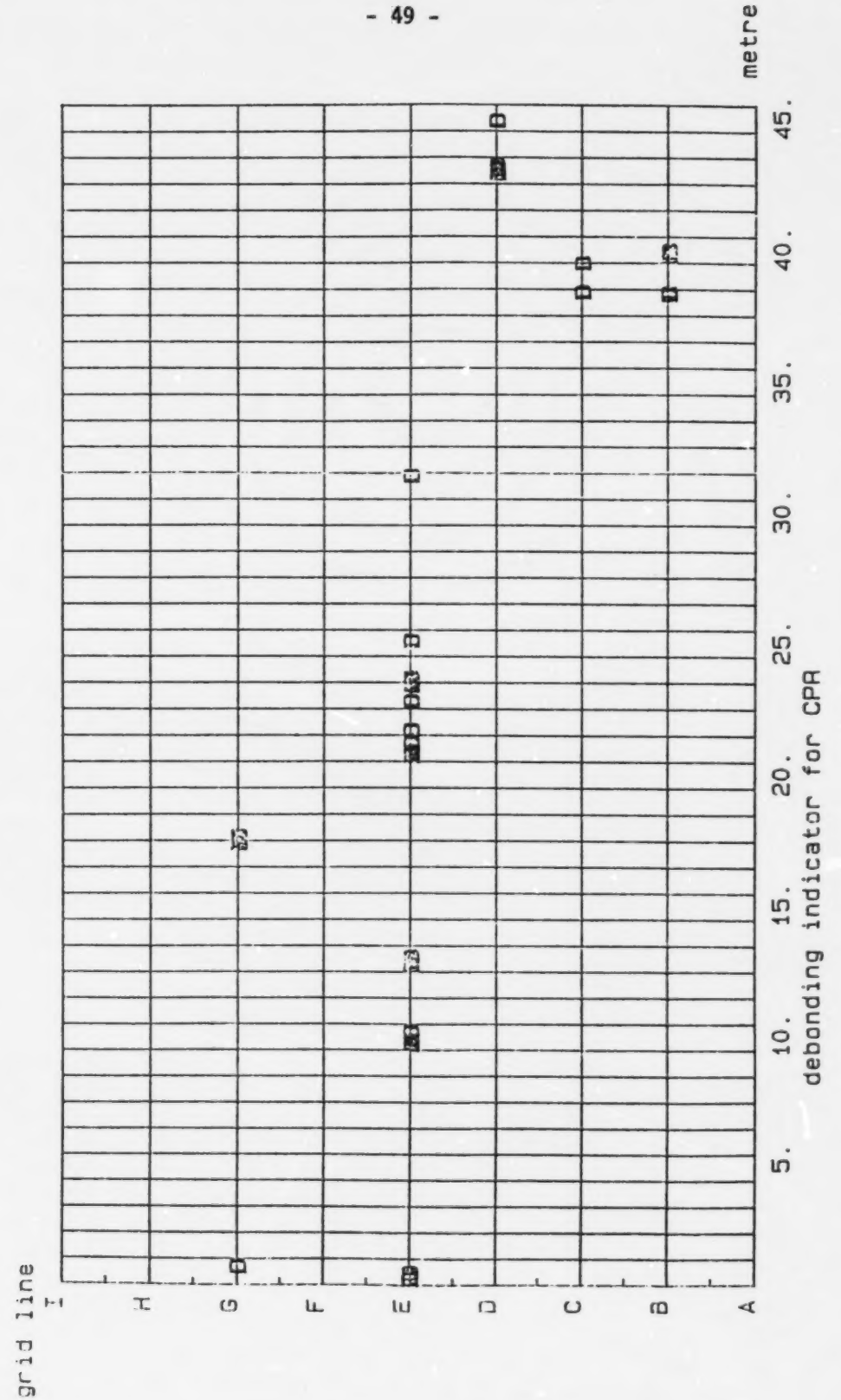


Figure 6.8/ Debonding Plot for CPR Overhead Using the DART System

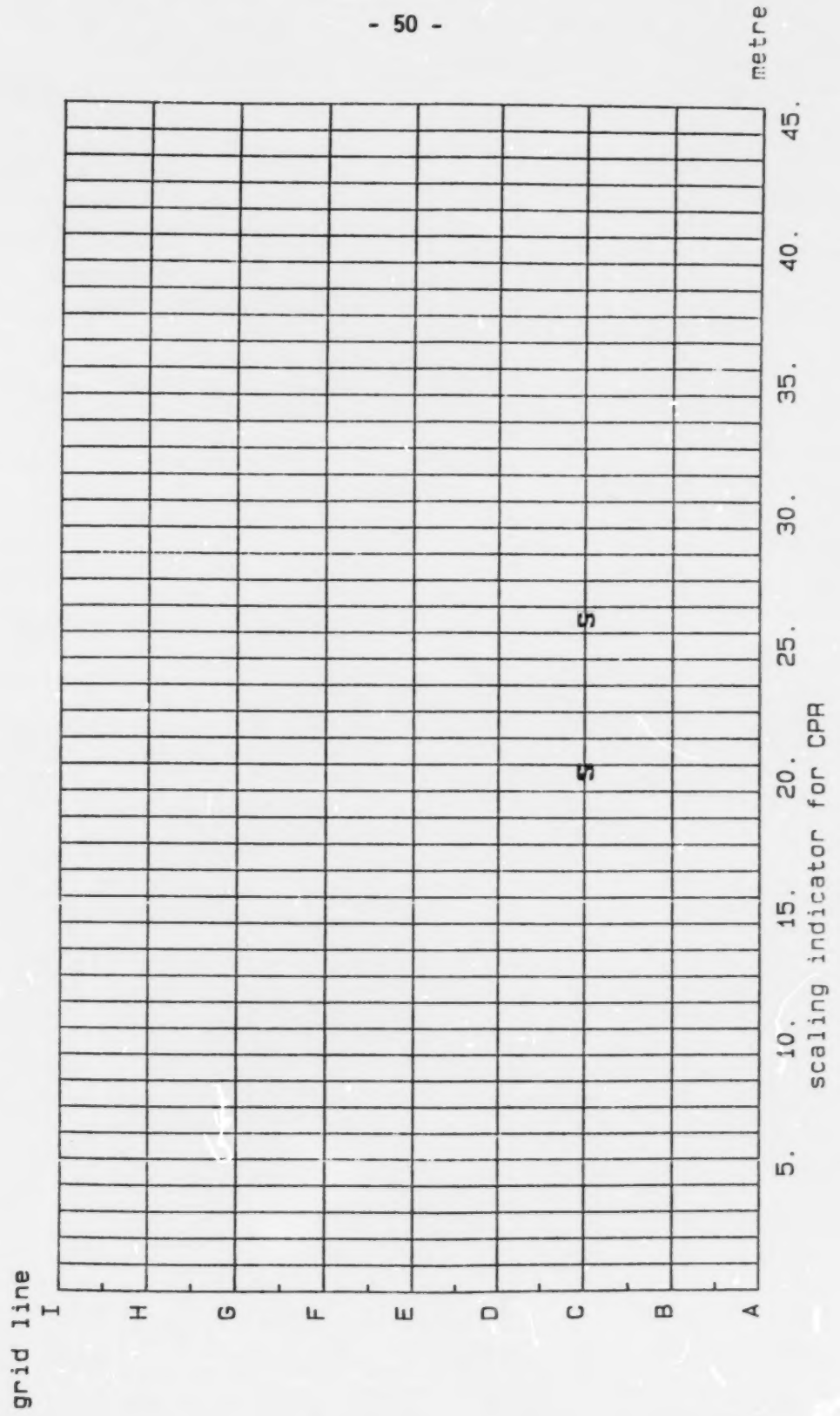


Figure 6.9/ Scaling Plot for CPR Overhead Using the DART System

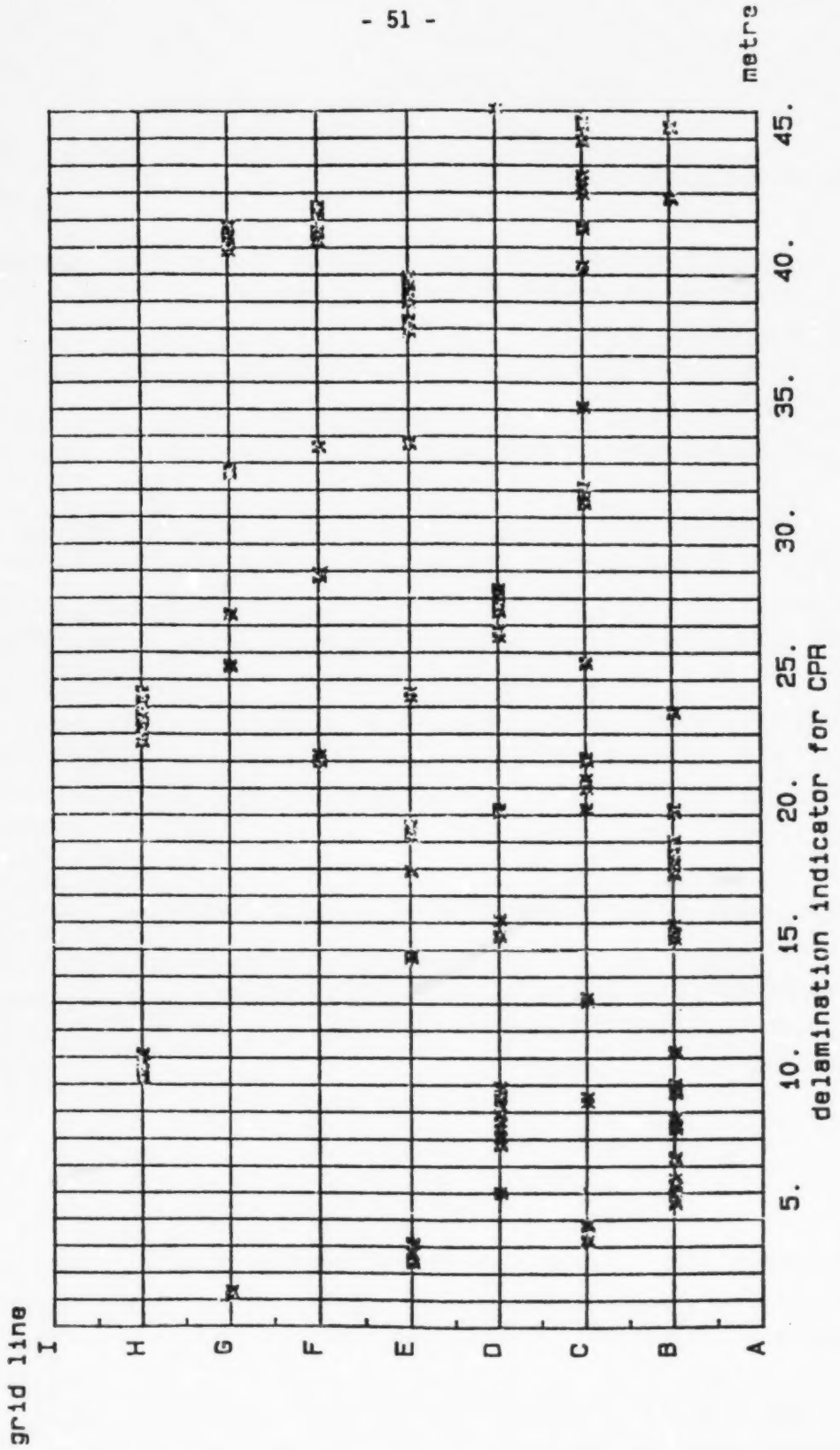


Figure 6.10/ Delamination Plot for CPR Overhead Using the DART System

7/ PROCESSING OF BURNHAMTHORPE OVERPASS DATA

7.1/ Collection of Data

Two site visits were made to Burnhamthorpe Overpass which is located at the intersection of Highway 427 and Burnhamthorpe Road. The overpass employs a voided concrete construction where hollow pipes are encased in the concrete. The bridge deck is exposed concrete and suffers from delaminations and other deterioration. There are several asphalt patches on the deck and some concrete patches.

In order to gain some insight to the reflections from a good bridge deck, a diagonal run was made (as illustrated in Figure 7.1) which cut across the voids. The intention of this was to determine whether the voids could be detected and their effect on the signal. Figure 7.2 illustrates the flat plate reflection and Figure 7.3 shows the reflections taken along the diagonal line at 0 m and 4 m. We see that in each case there is a strong surface reflection followed by some smaller variations in the waveforms. However, the reflections from the voids do not appear significant.

Two more sets of measurements were made. The first of these was to identify known areas of delamination and take spot recordings to be compared with areas of good concrete. The second set of measurements included runs along the length of the bridge deck with recordings being made using the fifth wheel.

7.2/ Sample Waveforms for Delaminated Concrete

Two areas of delamination were identified by chain drag and the high video waveforms were recorded. The waveform from one area, illustrated in Figure 7.4, can be compared to the signal from a good deck shown in Figure 7.5. Regretably, there is very little difference between the three waveforms. This is thought due to the fact that the reflection from the delamination is swamped by the transient from the surface reflection. For the case of asphalt overlay, the reflection from the asphalt-concrete interface is far smaller and, consequently, the reflection from the delamination is more distinct.

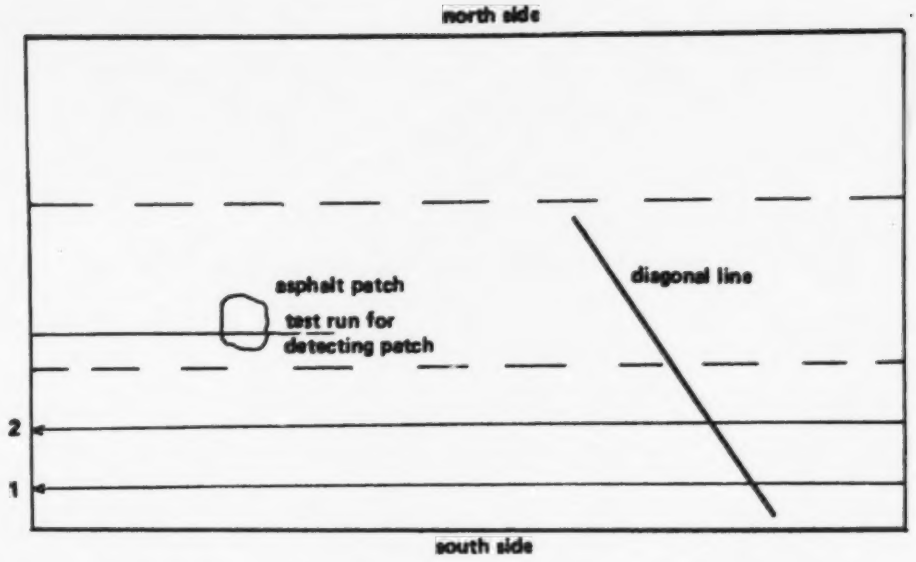


Figure 7.1/ Data Collection Passes on Burnhamthorpe Overpass
(Westbound Section)

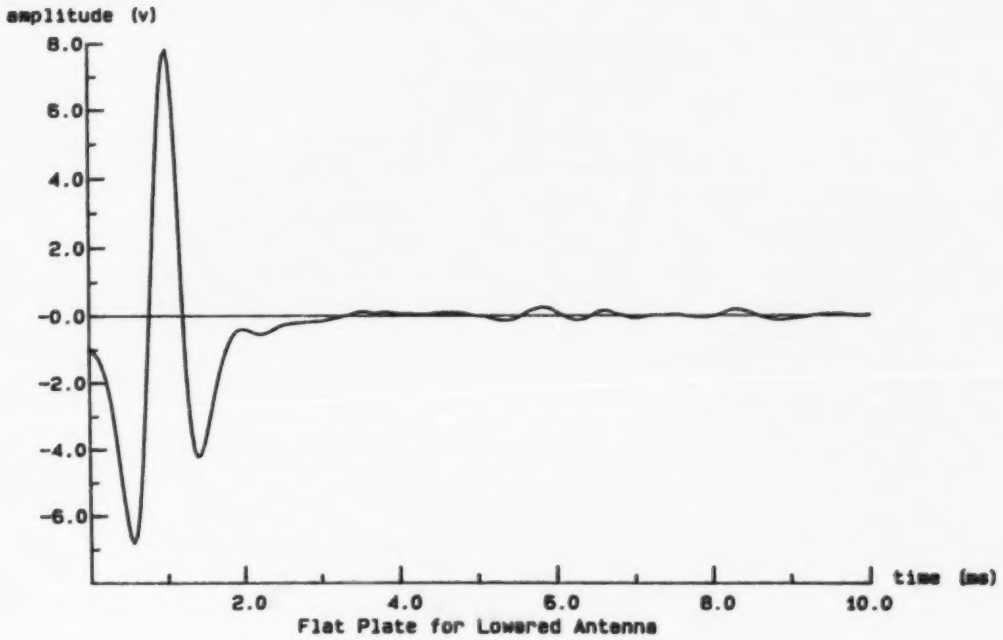
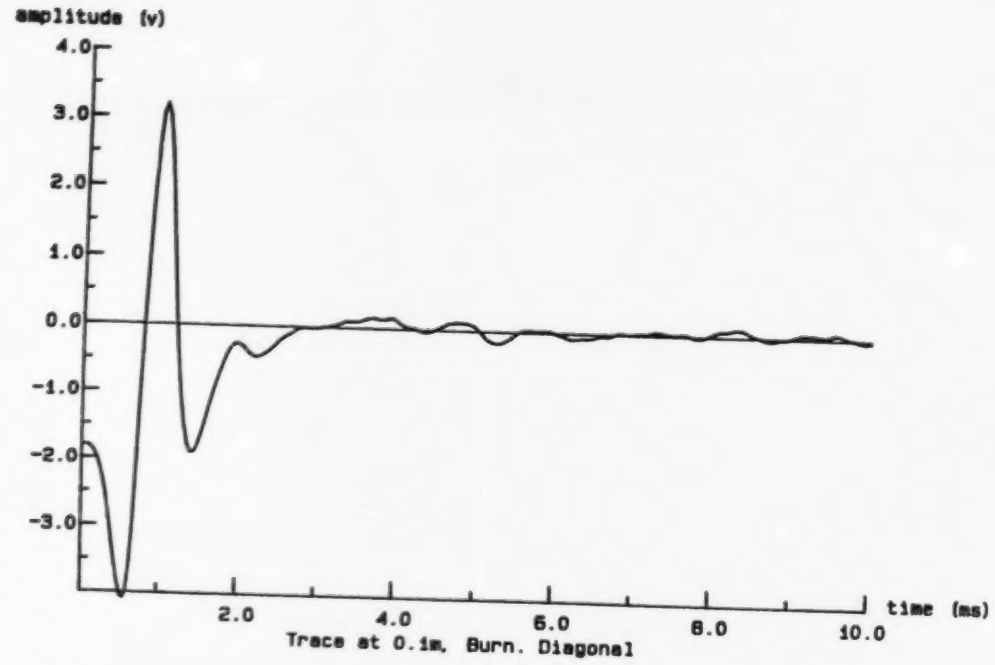


Figure 7.2/ Flat Plate Measurement



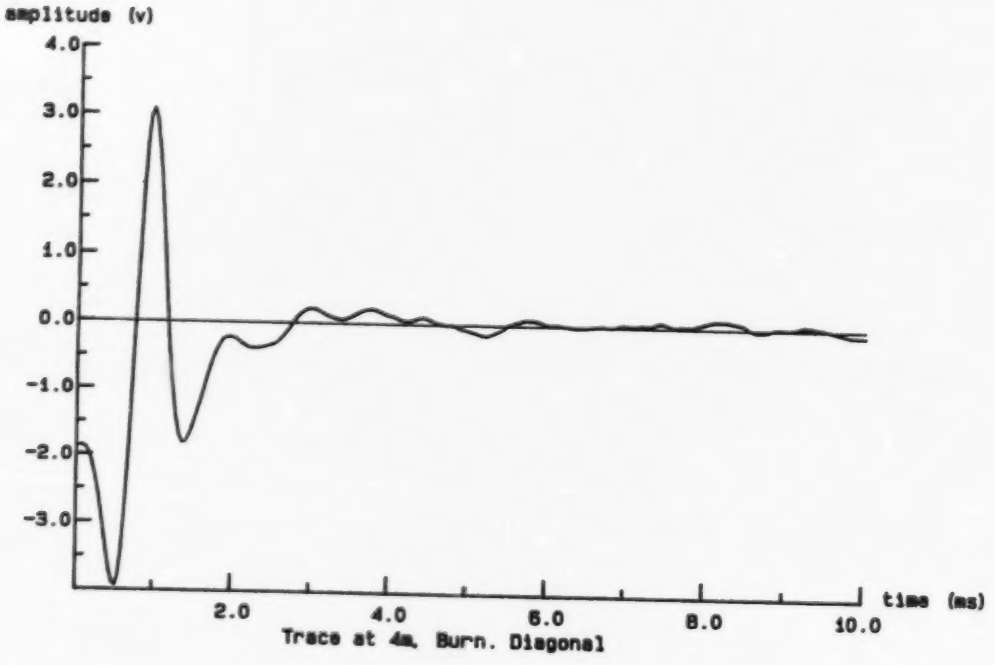


Figure 7.3/ High Video along the Diagonal Line for Good Deck

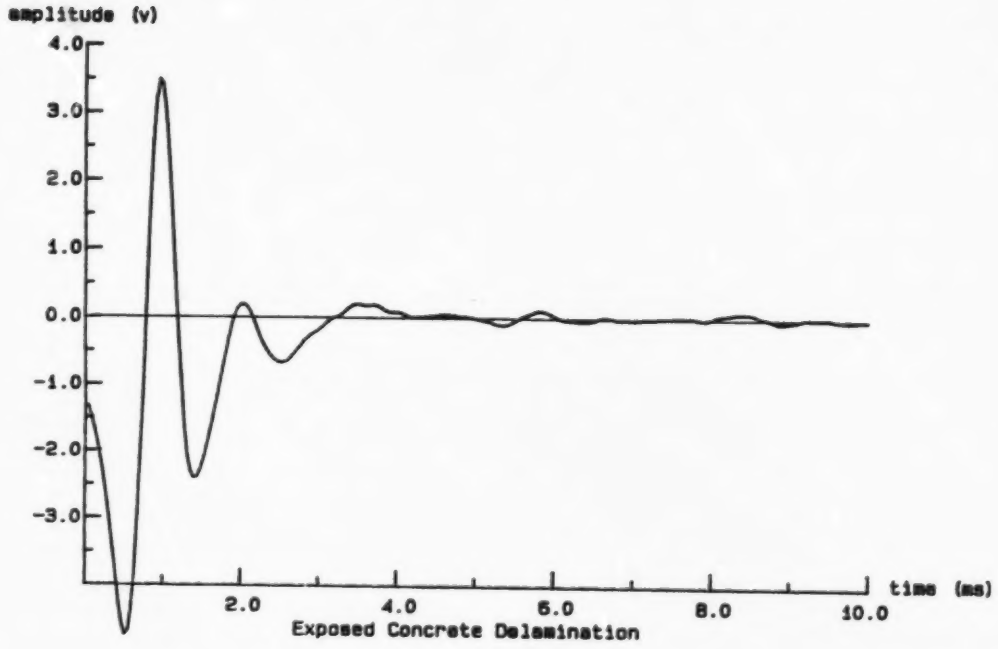


Figure 7.4/ High Video Return from Badly Delaminated Concrete

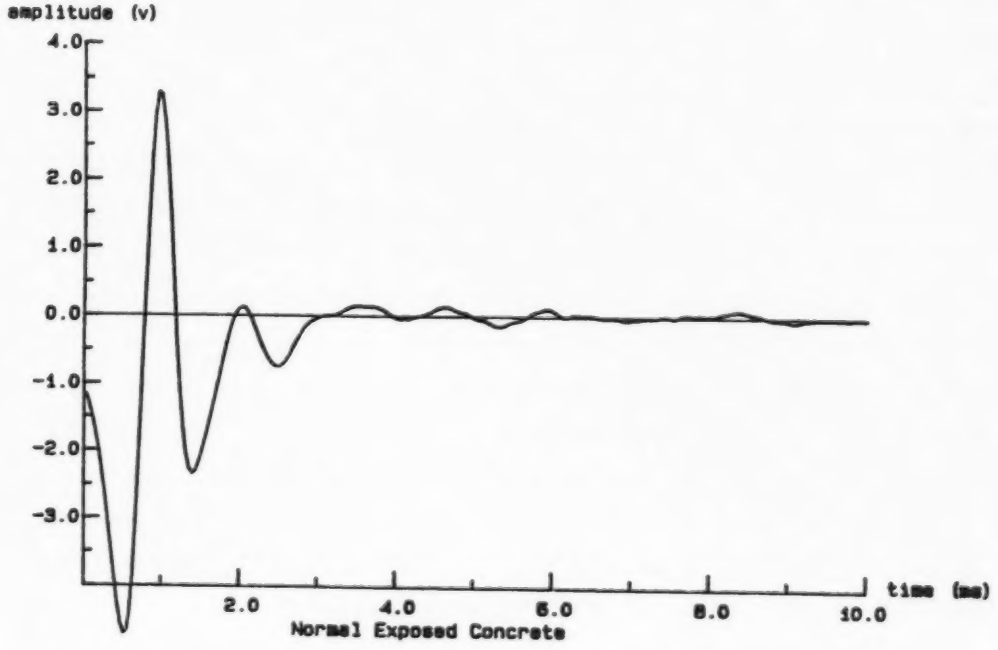


Figure 7.5/ High Video Return from Good Bridge Deck Structure

7.3/ Detection of Asphalt Patches

One run along the bridge deck passing over an asphalt patch, as indicated in Figure 7.1, was recorded and processed by measuring the dielectric constant. We see from Figure 7.6 there is little difficulty in detecting the patch since the change in dielectric constant is very significant. For purposes of comparison, Figure 7.7 plots the dielectric constant for line 1, identified in Figure 7.1, which has no patches.

7.4/ Slag Mix and Protection Board

While at the Burnhamthorpe Overpass, tests were conducted to determine the properties of slag mix and protection board. The radar antenna was raised in order to provide adequate clearance for the block of slag mix (approximately 30 x 50 cm) and the flat plate measurement was made, as illustrated in Figure 7.8. A sheet of protection board was then placed over the flat metal plate and the waveform of Figure 7.9 was recorded. The two waveforms of Figures 7.8 and 7.9 are very nearly identical, indicating that the protection board has very little loss.

With the protection board and flat plate removed, the reflection from the slag mix block was recorded, as illustrated in Figure 7.10. From the reflection coefficient, the dielectric constant of the slag mix is found to be approximately 4.8, which is well within the range of the other asphalt mixes. In order to test that the wave actually penetrates the block, a file was placed on top of the block parallel to the electric field and the reflection recorded, as shown in Figure 7.11. Comparing with Figure 7.10, we see that the file interacts strongly with the incident wave. Then, the file was placed below the slag mix block with the same orientation and the waveform was recorded, as illustrated in Figure 7.12. Comparing again with Figure 7.10, we see that the waveform following the surface reflection has changed considerably, indicating that the wave does in fact easily penetrate slag mix. Thus, we conclude that for all asphalt mixes tested in this project, the impulse radar signal has no difficulty in penetrating asphalt.

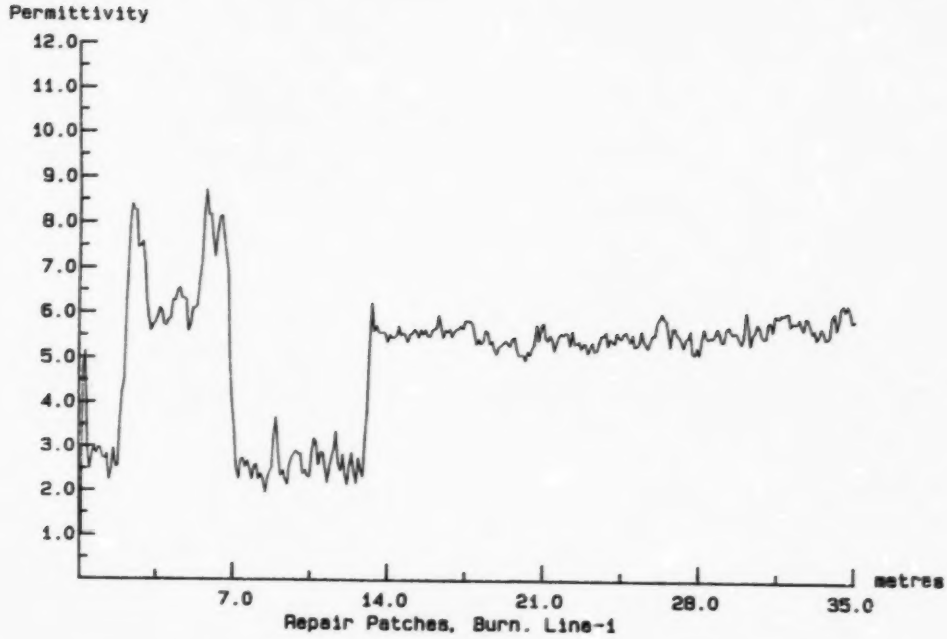


Figure 7.6/ Dielectric Constant Measurement of Surface Echo (Note the large change for the asphalt patch.)

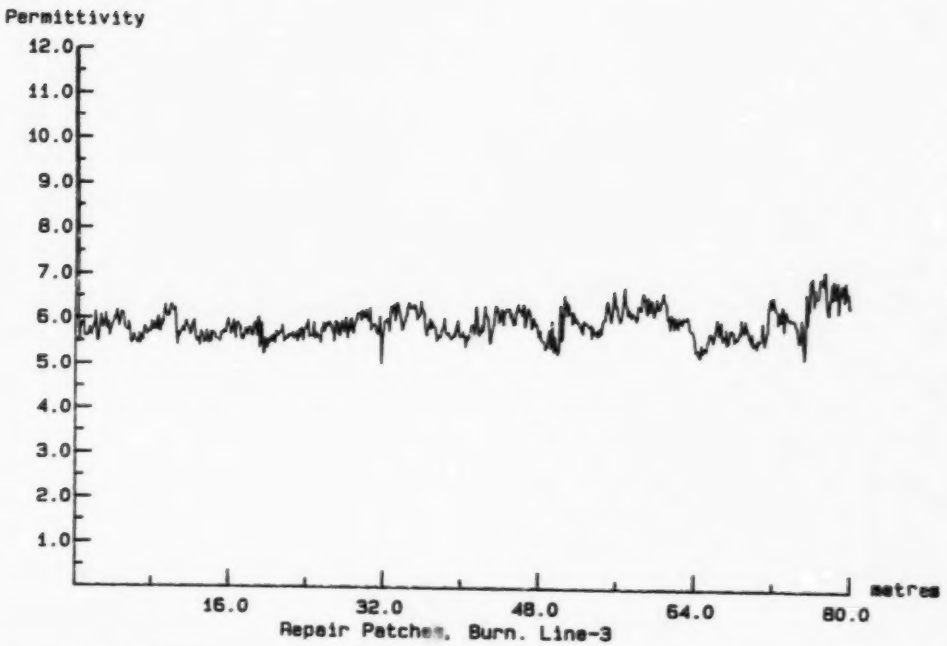


Figure 7.7/ Dielectric Constant Measurement for Line 2 with no Patches

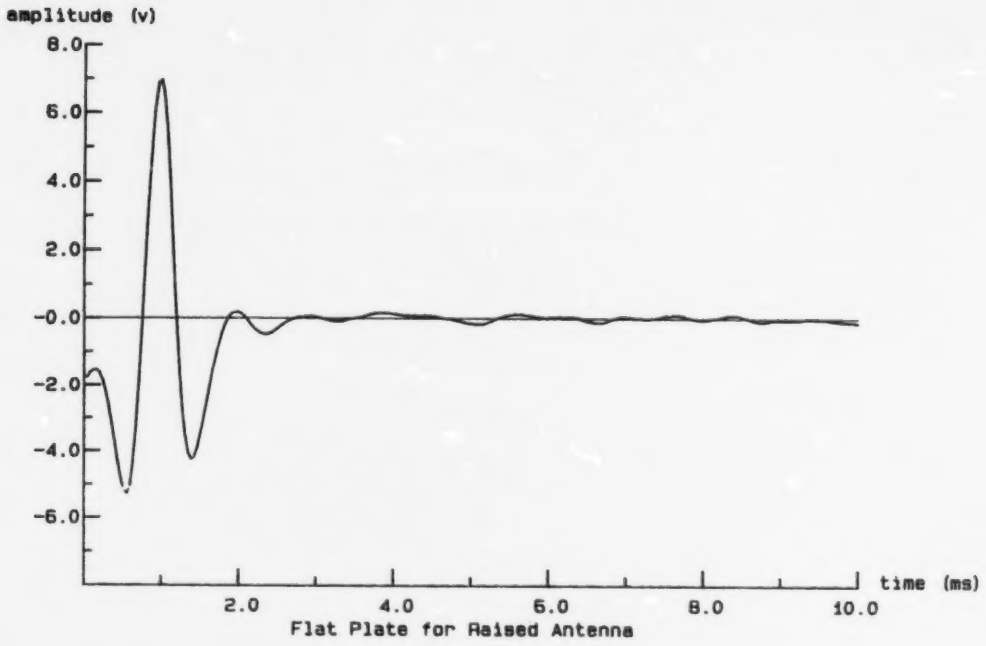


Figure 7.8/ Flat Plate Measurement for Slag Mix Test

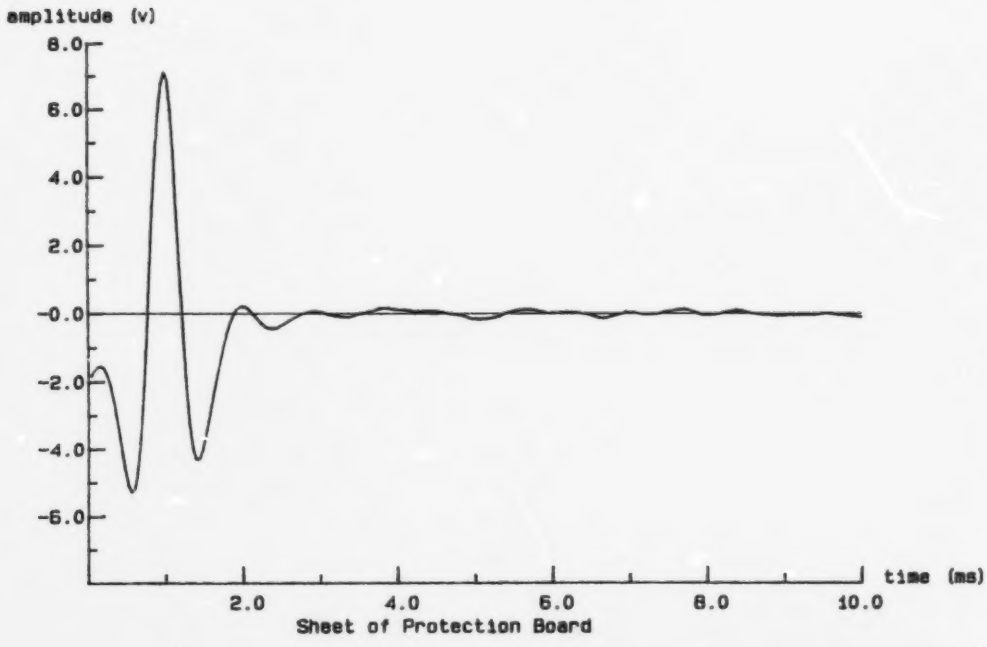


Figure 7.9/ Reflection from Protection Board Placed Over Flat Plate

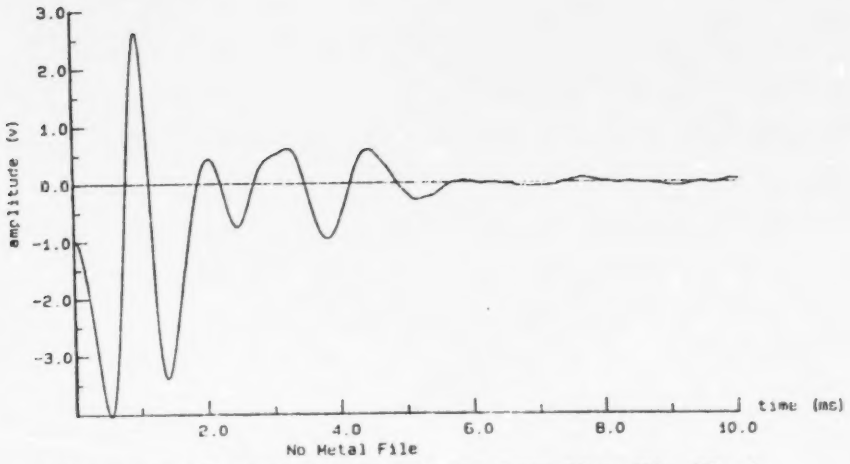


Figure 7.10/ High Video Return from Slag Mix Block

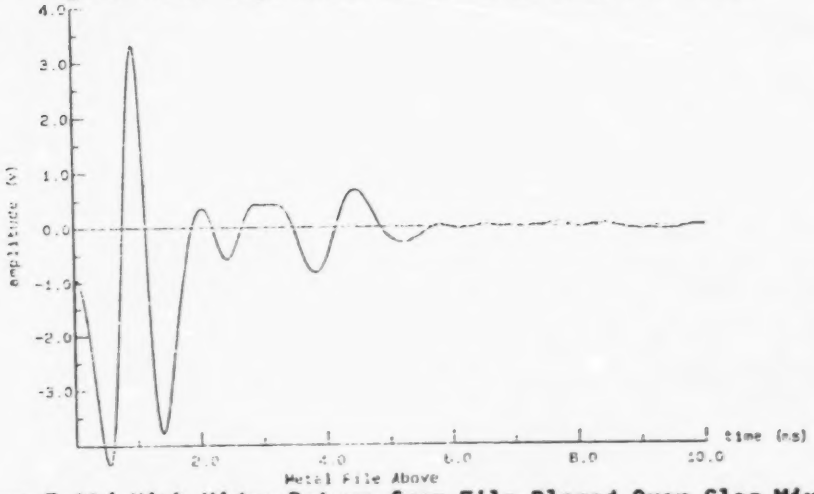


Figure 7.11/ High Video Return from File Placed Over Slag Mix Block

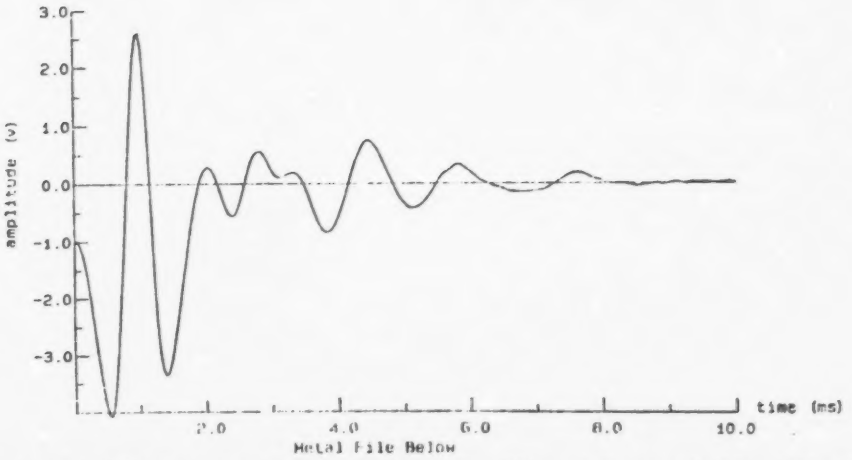


Figure 7.12/ High Video Return from File Placed Beneath Slag Mix Block

7.5/ Cracks in Concrete Deck

An attempt was made to detect vertical cracks in the concrete deck. Unfortunately, there does not appear to be significant change in the waveform when the antenna is over a crack. The reason for this is that the antenna footprint averages the reflection from the overall area and a crack simply is not significant to the total reflection.

8/ OPERATION

8.1/ Tape Recorded Data

The processing of tape recorded data can be accomplished by the following procedure:

1) Load tape into tape recorder and ensure that all connections to the computer are properly secured.

2) Initialize the computer by booting the system in order to load the programs from floppy disk. The monitor program will appear which then requests certain operator inputs such as number of lines, approximate line length, structure of the bridge deck and so on.

3) Activate the tape recorder so that the bridge line sync control signal on the tape recorder will automatically instruct the computer in processing the recorded data. The computer automatically loads the flat plate data and calculated the peak voltage in the waveform for dielectric constant measurements. Then the computer reads the data from the tape, one line at a time, and stores the data on the hard disk until all lines have been read.

4) The monitor program proceeds to process the data and store the results in files which can then be printed by the line printer or plotted by the plotter. It is estimated that the processing speed for the calculation is approximately 2 s per linear metre of bridge deck or 7.5 minutes for the six lines (each 75 m) of Nith River bridge deck. Plotting and printing are all in addition to this.

5) Bridge depth data are printed by the line printer and a plot of the scaling/debonding detector is provided by the plotter. Note that several sheets of plotting paper may be required by longer bridge decks and this will require operator assistance.

6) Once the output from the scaling/debonding detector is completed, the data file for delamination can be plotted. Here again, the plotter requires operator assistance if several sheets of plot paper are required.

8.2/ On-Board Van Operation

In this case, it is assumed that the plotter and printer are not used and the results are displayed on the monitor. In this case, the operation is somewhat simpler since it is further assumed that the hard disk is not employed.

1) Initialize the computer by booting the system in order to load the programs from floppy disk. The monitor program appears which then requests certain operator inputs such as approximate length of the line and structure of the bridge deck.

2) The van is positioned at the beginning of the line to be processed and the fifth wheel is positioned in contact with the deck surface. The operator activates the bridge line sync signal to indicate the beginning of the line (just as in normal operation) and proceeds to collect the data for the line. At the end of the line, the operator deactivates the bridge line sync signal to indicate the end of the line and the computer then proceeds to process the data.

3) Since only the data in computer memory can be processed with no storage on the floppy disk, the processing is very fast, with a processing speed of less than 2 s per linear metre being achieved. For example, one line of Nith River data takes approximately 2.5 minutes for a detailed analysis.

4) Results for asphalt depth are displayed on the monitor with the average depth being given as in the case of printed output. Results of the scaling/debonding detector and delamination detector are also fed to the monitor at the operator's request.

5) Items 2), 3) and 4) are repeated until all lines of the bridge deck are completed.

9/ CONCLUSIONS AND RECOMMENDATIONS

9.1/ Conclusions

The processing of bridge deck data by employing a system consisting of an special interface board to digitize data, a microcomputer equipped with a hard disk, a monitor display, a large computer memory, and printer/-plotter facilities has been particularly successful. The main advantages of this system over the previous system which used an HP 1000 computer include increased processing speed, ease of interface to the tape recorded data, flexibility in controlling the data flow to computer memory and disk storage, and simplicity of operation both in the laboratory/office or field environments. Specifically, the following are noted:

1) The new system is well suited in processing speed to the capabilities of the radar. For example, data are collected at a rate of approximately 1.5 m/s, and data processing requires approximately 2 s per metre. Thus, the time required to process any line is only marginally greater than the time taken to collect the data itself. This suggests that the DART system is neither underdesigned nor overdesigned.

2) Three different asphalt overlays were analysed in this project. Each was found to have its own peculiarities, although the measurement of asphalt depth in all cases was found to be straightforward. The differences lie in the subtleties of the reflection from the asphalt-concrete interface and the reflections from the rebars. The signal processing algorithms were thoroughly tested with these sets of data and the necessary changes made.

3) The impulse radar signal penetrates all asphalt mixes tested including slag mix. In addition, the signal passes through the protection board with little problem.

4) Vertical cracks in the surface do not give a significant change in the reflection. Thus, crack detection is not feasible.

5) Printouts and output plots are easy to understand and interpret. The computer removes almost all redundant data and pares the remaining traces to eliminate portions containing useless information. Selected waveforms can be obtained easily for visual inspection without having large amounts of irrelevant data.

6) The system is cost-effective in that the routine operations which can be better done by computer are all removed from the operator. This results in savings in time and personnel since only processed data outputs are presented. Another significant factor is that, for this application, a relatively low-cost system is capable of replacing an expensive minicomputer.

7) The system may be expanded at any later date. This is significant from the standpoint that new boards are always being developed for IBM and IBM-compatible microcomputers.

8) The system is software upgradable and will be capable of running new software packages which will appear in the marketplace.

9.2/ Recommendations

It is recommended that:

1) The system be thoroughly field tested to gain further insight to the variations in parameters which can occur.

2) Selected sets of data be analysed to provide a deeper understanding of the reflections from the various fault conditions.

3) The effects of vehicle speed be examined to determine the maximum speed of operation. At present, there is a large amount of redundant data which is discarded by the computer.

4) The on-board computer be used to control the speed of the vehicle in order to remove the speed control problem from operator responsibility. This would permit the operator to concentrate more fully on the accuracy of steering the vehicle.

5) Further theoretical analysis be conducted and a computer model be formulated in order to support the program.

REFERENCES

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